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Forecasting the Demand Potential For STOL Air Transportation

**Shing-Leung Fan, Robert Horonjeff,
Adib Kanafani, and Abdollah Mogharabi**

FEBRUARY 1973

**Prepared for
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION**

Contract No. NAS2-6717

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(NASA-CR-114572) FORECASTING THE DEMAND
POTENTIAL FOR STOL AIR TRANSPORTATION
(California Univ.) 127 p HC ~~12-64~~

N73-22932

CSCL 05C

Unclas

G3/34 69835

N73-22932

FORECASTING THE DEMAND POTENTIAL
FOR STOL AIR TRANSPORTATION

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Prepared under Contract No. NAS2-6717 by
INSTITUTE OF TRANSPORTATION AND TRAFFIC ENGINEERING
UNIVERSITY OF CALIFORNIA, BERKELEY

for

AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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PREFACE

The study documented in this report is aimed at developing a methodology for forecasting the demand potential for Short Take-off and Landing (STOL) air transportation. The study consists of the construction of a system of demand models, and of calibrating them using data on the San Francisco-Los Angeles air travel Corridor. The calibrated models are used to forecast the demand potential for postulated STOL systems with varying configurations in the study corridor.

The concept of demand forecasting by sensitivity analysis is used in this study. This concept, recognizing the difficulty of specifying exact characteristics of future STOL systems, permits forecasting on the basis of ranges of variables that describe the possible technological and service characteristics of STOL. Forecasts through 1990 are presented in this report and are based on a range of economic and demographic trends in the study area.

Throughout this study, valuable assistance and guidance was provided by the staff of the Ames Research Center, National Aeronautics and Space Administration. For this the authors wish to acknowledge their appreciation. Particular thanks are due to the study Technical Monitor, Mr. George Kenyon, for his continued support.

Valuable information was obtained from the data files of two companies who generously extended their use for this study. The authors wish to acknowledge their thanks to Daniel, Mann, Johnson, and Mendelhall (DMJM), and to Landrum and Brown.

A number of graduate students and analysts contributed to the conduct of this study, in addition to the authors. Philip H. Agee conducted valuable research on travel characteristics; Marvin Tsao, contributed valuable computer analysis services. Both these contributions are acknowledged.

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CHAPTER 1

INTRODUCTION

Purpose

The purpose of the study documented in this report is to develop a process by which the demand potential for Short Take-Off and Landing (STOL) air transportation can be estimated. The study is aimed at providing a conceptual framework and an analytical methodology for estimating the potential share of the air transportation market that different STOL system configurations can be expected to capture. This is necessary for the evaluation of the economic feasibility of STOL transportation.

STOL transportation is defined as a special mode within air transportation because (1) STOL aircraft can use shorter runways and can navigate in more restricted airspace than conventional aircraft, and (2) STOL aircraft have a limited operating range, making them suitable primarily for short haul air transportation.

The requirements of the study were to provide a calibrated and tested system of demand models, and to demonstrate the application of these models in forecasting the demand potential for a set of postulated STOL systems serving a short haul air travel corridor, namely the corridor between the Los Angeles and San Francisco Metropolitan Areas.

Conceptual Framework

The potential market for STOL depends on three major factors. One factor is the environmental, political, and economic constraints that

may limit the feasibility of locating STOL-ports in urban areas. If such ports cannot be located, then STOL transportation will lose what appears to be two of its main advantages. Namely (1) accessibility to points of travel demand, and (2) the advantage of reduced delays and congestion that could be achieved by diverting STOL traffic from the large metropolitan airports to the STOL-ports.

Second, the demand potential for STOL depends on its economic as well as operational characteristics. In other words, the market share for STOL is influenced by the modal characteristics of STOL relative to those of other modes serving the same market. This is particularly important in this context of high density short haul travel, for it is in these markets that high speed ground transportation may create real competition.

Third, the market potential for STOL is strongly dependent on its technological characteristics of STOL aircraft. In addition to influencing the attractiveness of STOL as an air transportation mode, these characteristics determine the environmental impact of STOL operations and can determine the extent to which such operations can be proliferated.

In view of the above considerations, it is clear that a complete specification of a STOL transportation system is needed before an assessment can be made of its demand potential. Since STOL systems do not exist presently, it is not possible to use actual system characteristics and configurations for the forecasting process. For this reason, the concept of forecasting by sensitivity analysis is introduced.

Recognizing the difficulties of specifying the exact characteristics

of prospective transportation systems, this concept allows forecasting to proceed in the following manner. A number of transportation variables are defined to describe the characteristics of the transportation system. These variables are introduced into a model that relates them to the demand for transportation. The models are calibrated on the basis of available data on existing systems. If successful calibrations are obtained, then these models can be used to forecast the demand for the prospective transportation modes by sensitivity analysis. Sensitivity analysis includes specifying reasonable ranges for the transportation variables included in the model. They indicate the ranges of possible technological characteristics that the prospective transportation mode may be expected to have. The models are then used to provide forecast ranges of the demand potential for the mode.

In the application of this approach to forecasting the demand potential for STOL transportation, a number of variables describing air transportation services are specified. These include travel times, travel costs, and schedule frequencies. Models relating these variables are then calibrated using available data on CTOL air transportation. The models are then applied to forecast the demand potential for STOL systems with varying characteristics as specified by ranges of the variables.

The choice of variables is crucial to the validity of this approach. It is clear that the use of variables that are particular to specific transportation modes cannot be extended to other modes. In this study, it is postulated that STOL and CTOL are both air transportation modes that are not drastically different, at least not as far as the travellers

are concerned. Therefore, models calibrated using data on CTOL transportation can be used to estimate the demand for STOL transportation.

Analytical Framework

The modeling structure used in this study consists of two major parts. The first part includes the development of a travel generation model. The purpose of this model is to estimate the total demand (both CTOL and STOL) for air transportation within a study area. The second part includes the development of a choice model. This model describes the process by which air travellers chose among alternative air travel modes. The choice model is aimed at estimating the potential market share that STOL routes of different service characteristics would capture.

Naturally, these two models are related. The total demand for air transportation is dependent on the transportation system characteristics. This means that the specification of systems characteristics including STOL, is necessary for the use of both the travel generation and the choice models. Therefore, this approach recognizes the fact that the introduction of STOL service in an area will affect the total travel demand generation, as well as the distribution of the demand among available routes; in other words, it recognizes the impact of the introduction of STOL service on both diverted traffic and induced traffic.

The modeling framework used in this study is shown in Fig. 1.1. In this figure a flow chart describes the way in which the outputs of both models, operated simultaneously, are combined to provide the required output, which is a demand forecast for STOL transportation.

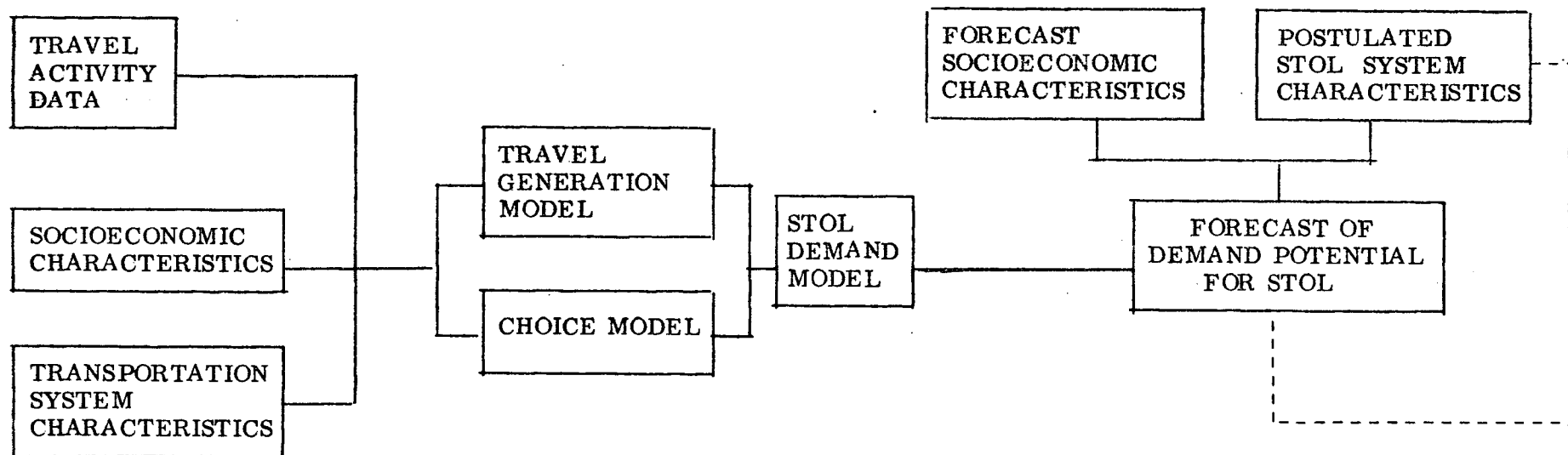


Figure 1-1 Model Framework

The figure also describes the flow of information into the different models. Information on existing system characteristics and on the socio-economic characteristics of the potential users of the transportation system, as well as information on observed traffic flows are also needed to calibrate and to test the validity of the models.

The feedback indicated in the figure represents the fact that the demand potential for a transportation system influences the design and, consequently, the characteristics of the system. These characteristics in turn influence the demand potential of the system. While this feedback is recognized conceptually, it has not been included in the models of this study for two reasons. First, to model the feedback process requires that accurate information be available on the technical and economic characteristics of STOL aircraft. As an illustration, consider the process of feedback between frequency of service, air fare, and demand for a STOL system. For a given demand level, there is an optimal schedule frequency that STOL system operator would offer at any given fare. This frequency is the one that maximizes the profit to the operator subject to the physical constraints on the system. In order to describe the relationship between demand level and optimal frequency, a detailed model of the economics of STOL system operation must be constructed. Without such a model it is not possible to analyze the influence of demand on frequency and to describe the feedback process. Detailed information for such a model was not available.

The second reason is that the forecasting process is performed in the form of a sensitivity analysis. Therefore, to include the feedback process is not very crucial, since it is always possible to study the

demand potential within ranges that include the equilibrium of any feedback process. Thus when sufficient information becomes available about the nature of the feedback between demand and transportation characteristics, it is possible to use the results of the forecasts to search for the equilibrium.

The Study Area

In order to provide an empirical base for the models used in this study a study area was selected. This was the California Corridor consisting of the San Francisco Bay Area, and the Los Angeles Basin, shown in the map of Fig. 1-2. The choice of study area was based on a number of factors. First, data was available on the travel characteristics in this area. Second, the San Francisco Bay Area and the Los Angeles Basin are two large metropolitan areas with multiple airport systems. Furthermore, the corridor connecting the two areas is a high density short haul air travel corridor, with a distance of about 400 miles and a 1970 annual volume of about 3.5 million air passengers. Therefore, this corridor is a potential candidate for the introduction of STOL transportation.

In this study demand forecasts are performed for a number of different STOL system configurations postulated in the study area. These configurations are defined by selecting alternative STOL-port locations within the San Francisco and the Los Angeles areas.

Outline of the Report

This report consists of six chapters that describe the models used and some of the results of their application. An appendix under separate cover includes (1) detailed descriptions of the development of the



Figure 1-2 Study Area

data base; (2) numerical techniques and computer programs used in the analysis; and (3) detailed results of the sensitivity analysis.

Chapter 2 of this report discusses the design of the models used in the process: the travel generation model, and the choice model. It also discusses the combination of these two into a STOL demand model. Chapter 3 describes the data base used for the calibration of the models. The discussion includes the data acquisition and data reduction phases of the development of the data base. This chapter also includes some summaries of travel characteristics obtained by a study of the available information. Chapter 4 describes the process of using the data base for the calibration of the models. The results of the statistical analysis are presented in the chapter. Chapter 5 describes the use of the calibrated models for forecasting the demand for air travel in the study corridor, and the market shares of potential STOL system configurations. Finally, Chapter 6 synthesizes the results and conclusions of the study and discusses some potential directions for further research in the field of demand forecasting for STOL air transportation.

CHAPTER 2

MODEL DESIGN

Introduction

The modelling structure described in the previous chapter consisted of two basic models aimed at estimating the demand potential for STOL air transportation. These two models are, first, a total air travel generation model, which generates the total air travel demand in the California corridor, and second, a choice model, which estimates the process by which air travelers choose among available air transport alternatives. This chapter describes the two models and their use in combination to provide a demand model for STOL air transportation.

Air Travel Generation Model

In designing a model for air travel generation a number of factors were taken into consideration. First, some features that would be desirable in an ideal demand model were eliminated at the travel-generation stage because, as a practical matter, required data was not available. Second, the idea of using a longitudinal model which would be most suitable for the purpose of forecasting had to be set aside. A longitudinal model uses observations at different points in time and attempts to trace, in a dynamic manner, the evolution of demand for transport, based on selected determinants of that demand. But to structure and calibrate such a model would, it was felt, require an effort much beyond the scope of the present study. So instead, a simple cross-sectional model was employed.

A cross-sectional model is constructed and calibrated on the basis of observations taken at one point in time. For forecasting purposes, some of the demand characteristics included in the model are assumed to remain unchanged during the forecasting period. Demand forecasting then proceeds by using exogenous forecasts of the other characteristics. Needless to say, this approach cannot be expected to yield forecasts that are absolutely reliable. It should be used only to give the analyst some insights into the determinants of travel demand and into the possible trends that may be expected.

This study is concerned with the corridor connecting the San Francisco Bay Area (SFBA) and the Los Angeles Basin (LAB). A number of transport modes are now serving this corridor. These include both air and ground transport. One way of going at the estimation of STOL demand would be to take all these modes into account. While this might be the preferable procedure in principle, it introduces complications which it was felt could, without significant loss of realism, be avoided for purposes of this study by regarding present ground transportation in the corridor as serving a market that would be insensitive to the addition of STOL. The simplification would not hold, however, if technological changes in ground transportation were introduced. It would then be imperative to study the competition between ground and air transportation. Although the model is thus limited to air transportation, it can be seen from the model description that only slight modifications are required to introduce ground transportation characteristics. Such modification would of course be contingent on the availability of ground transportation data that

was compatible with the existing air data. Such ground data are not presently available.

The air travel generation model used in this study postulates that the total number of air trips demanded between any pair of origin and destination locations at either end of the corridor is a function of two sets of variables:

1. Socio-economic Variables: These variables are used to describe the levels of socio-economic and land-use activities that take place at the two ends of the trip, the main hypothesis being that transportation is a function of these activities. The variables included are: population, income, and employment.

2. Transportation Variables: These variables are used to describe the level of service provided between any pair of potential trip ends. The hypothesis here is that the number of trips actually undertaken will depend on the service available (in addition to the socio-economic variables). The variables included are: total travel time (including access time and line-haul time), the frequency of service, and total trip cost.

The general form of the air travel generation model is logarithmic or multiplicative in nature. This form has the advantage of being amenable to simple statistical estimation. It also allows a simple interpretation of parameters: as constant demand elasticities.

Generally, if T_{ij} is the total volume of air trips between city i and city j at different ends of the corridor, and if X_k represents a vector of socio-economic variables and t_p a vector of transportation variables

then the model is specified as follows:

$$T_{ij} = f(X_k, t_p) \quad (2.1)$$

In particular three different forms were specified and later validated statistically. These were:

$$T_{ij} = \alpha_0 P_i^{\alpha_1} P_j^{\alpha_2} Y_i^{\alpha_3} Y_j^{\alpha_4} t_{ij}^{\alpha_5} \quad (2.2)$$

$$T_{ij} = \alpha_0 P_i^{\alpha_1} P_j^{\alpha_2} Y_{ij}^{\alpha_3} t_{ij}^{\alpha_4} \quad (2.3)$$

$$T_{ij} = \alpha_0 P_i^{\alpha_1} P_j^{\alpha_2} Y_{ij}^{\alpha_3} LS_{ij}^{\alpha_4} \quad (2.4)$$

where T_{ij} is the total traffic between i and j as before,
 P_i, P_j are the populations at i and j,
 Y_i, Y_j are the median income levels at i and j,
 Y_{ij} is an average median income for both cities i and j,
 (this average can be simple or weighted)
 t_{ij} is the shortest total travel time between i and j,
 and LS_{ij} is the level of services between i and j as described
 below.
 and α_i are parameters representing the elasticities of the
 demand to the respective variables.

The level of service variable is defined to incorporate all of the three transportation variables included in the model; trip cost and frequency of service. The variable was defined as follows:

$$LS_{ij} = \sum_k (F_{ijk}/C_{ijk} H_{ijk}) \quad (2.5)$$

where F_{ijk} denotes the total available schedule frequency between i and j by mode k

C_{ijk} is the trip cost between i and j by mode k

and H_{ijk} is the total travel time between i and j by mode k

It should be noted that the notation k for mode is not intended here to include the ground transportation mode. A mode in the context of the model denotes a particular airport pair. As there are a number of airport pairs that can serve a given city pair in the corridor, these are treated as if they were different modes in an abstract sense. The transportation characteristics variables, C , H , and F , are considered sufficient to completely describe the six characteristics of each of the modes. As mentioned earlier, a modification to include all available transport modes in the model could be introduced by enlarging the domain of the index k .

As designed, the model described in Eqs. (2.2) - (2.4) is specified separately for each trip purpose. As described in Chapter 4, the model was calibrated separately for business travellers and for

non-business travellers. This was done because the results of statistical analysis of the available data have shown that these two groups of travellers have significantly different travel generation characteristics. It is for simplicity that trip purpose is not shown as an index in the model formulation.

As shown in Eqs. (2.2) - (2.4) the shortest available travel time and the total weighted level of service between any city pair are determinants of the total demand. It is to be expected a priori that as the total travel time, for example, is reduced the travel generation will increase. The model is therefore, a demand model that accounts for traffic induced by systems improvements. The nature of the market split among available modes, is the subject of the next model to be discussed, i.e. the Choice model.

The Choice Model

The purpose of the choice model is to describe a process by which an air traveller chooses among alternative services available in his travel demand corridor. The model design used here is intended to provide a framework for estimating the potential share of the market that a STOL service would take if it is introduced. The model is a stochastic model which allows the aggregation of trip makers in a manner that takes into account the differences among individual tastes and travel decision processes. Basically, the model predicts the probability that an individual traveller chooses a given alternative for his trip as a function of weights he places on the various attributes of that alternative. In aggregating this choice

process to include all travellers in the corridor, the weights placed on the various attributes of transportation service are treated as random variables. The distribution functions of these random variables are postulated to represent the differences among individual travellers. These functions are estimated statistically from observed data. The estimation procedures are described in Chapter 4. This approach allows the aggregation of travellers without masking any of the variations amongst them. Previous methods of transport demand analysis employed values averaged over large groups of the travelling population. This averaging often led to the masking of variations within aggregated groups.

In order to facilitate the presentation of the choice model, the following notation is used:

1. Route: A route is defined as a transportation link connecting two airports in a study corridor. A route is defined to exist only when scheduled air service is available between the two airports.
2. Node: A node is the representation of an airport in the study corridor. A node may be either a CTOL or a STOL airport. An airport with both STOL and CTOL service is represented by two nodes at the same location.
3. Subnode: A subnode is the representation for a trip end in the study corridor. In other words, a trip origin or a trip destination are represented by subnodes. Subnodes may be used to denote actual trip ends such as a dwelling or an office, or groups of such trip ends in one analysis zone, such as a city and a group of

cities.

4. Trip: A trip would consist of a journey between two subnodes via a pair of nodes that are connected by a transportation link.

Figure 2-1 shows a graphical representation of a corridor. A and B are subnodes in metropolitan areas I and II at both ends of the corridor. C,D,E,F,G,H,K, and M are nodes of which C and D are STOL-ports; H and G are conventional CTOL airports; and E and F represent an airport with both STOL and CTOL service, the same is true of K and M. In the corridor illustrated in Fig. 3-1 there are a total of 5 routes. These are CD, EG, EK, FM, and HK. A trip is a journey from A to B, (or vice versa) via any of these five routes, such as A-CD-B.

With this notation, the structure of the model can now be described. The probability of an individual traveller choosing a given route is assigned on the basis of a set of characteristics of this route as well as the other routes available. Implicit in this is the assumption that the factors that affect the traveller choice process can be represented by a set of route characteristics. If we define

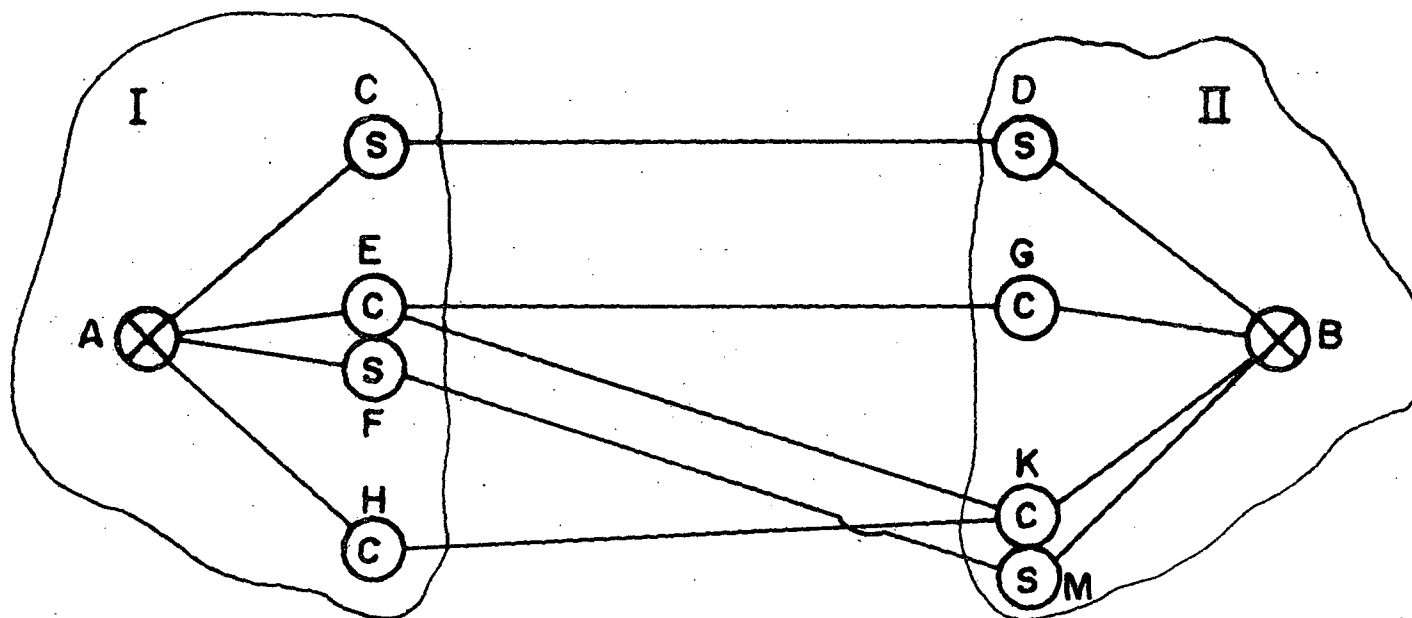
P_{ijk} as the probability of choosing route k for a trip between i and j, and

$Y_{ijk1}, \dots, Y_{ijkm}$ as m characteristics of the route k for travel between i and j,

then the choice model can be stated as:

$$P_{ijk} = g(Y_{ijk1}, Y_{ijk2}, \dots, Y_{ijkm}) \quad (2.6)$$

The specification of the model is completed when the functional



Legend

- (C) Airport with both CTOL and
- (S) STOL services
- (C) Airport with CTOL services
- (S) Airport with STOL services
- (X) Trip end

Figure 2-1 Graphical Representation of a Corridor

relationship $g(,)$ is completely defined. In particular, we are interested in representing the weights that a traveller places on the different characteristics Y . An individual traveller is assumed to evaluate the characteristics of all routes one at a time. For each characteristic the traveller ranks the routes available to him. This ranking is analogous to the probability that a route is chosen on the basis of this particular characteristic. It will be assumed that there is a unique correspondence between the ranking of a route, on the basis of a characteristic and the probability of choosing this route on the same basis. This correspondence is defined by a set of weights θ_l . Therefore, letting A_l be the event of choosing a route on the basis of characteristic l the choice probability $P_{ijk l}$ is given by:

$$P_{ijk l} = P(A_l) \quad (2.7)$$

Now, a relationship between the weight θ and the probability P is postulated. This relationship is the well known Sigmoid function which seems to be a good way to represent changes in probability as brought about by changes in θ . Thus

$$P_{ijk l} = P(A_l) = \frac{\theta_l Y_{ijk l}}{\sum_r \theta_l Y_{ijr l}} \quad (2.8)$$

In the above expression the decision of taking route k on the basis of a given attribute $Y_{ijk l}$ is a function of both route k and all routes available. Since θ varies among individual trip makers, it is specified as a random variable. It is important to note that

$P_{ijk\ell}$ in Eq. (2.8) is the probability based only on one attribute ℓ and is independent of all other route attributes. Therefore, $P_{ijk1}, P_{ijk2}, \dots, P_{ijk m}$ are probabilities of independent events. The total choice probability P_{ijk} which is based on all route attributes is generated by combining all the probabilities $P_{ijk\ell}$. This is done as follows:

$$\begin{aligned}
 P_{ijk} &= P[\text{choosing route } k \text{ on the basis of attributes} \\
 &\quad 1, 2, \dots, m] \\
 &= P[A_1 \cap A_2 \cap \dots \cap A_m] \\
 &= P[A_1] P[A_2] \dots P[A_m] \\
 \text{or, } P_{ijk} &= P_{ijk1} P_{ijk2} \dots P_{ijk m} = \prod_{\ell=1}^m P_{ijk\ell} \quad (2.9)
 \end{aligned}$$

By combining Eqs. (2.8) and (2.9) we obtain:

$$P_{ijk} = \prod_{\ell=1}^m \frac{Y_{ijk\ell}^{\theta_{\ell}}}{\sum_r Y_{ijr\ell}^{\theta_{\ell}}} \quad (2.10)$$

subject to

$$0 \leq P_{ijk} \leq 1 \quad (2.11)$$

and

$$\sum_k P_{ijk} = 1 \quad (2.12)$$

From (2.10) it is obvious that (2.11) is satisfied. In order to satisfy (2.12) we introduce a factor K_{ij} in (2.10) which yields

$$P_{ijk} = K_{ij} \prod_{\ell=1}^m [Y_{ijk\ell}^{\theta_{\ell}} / \sum_r Y_{ijr\ell}^{\theta_{\ell}}] \quad (2.13)$$

with (2.13) and (2.12) it should be possible to determine K_{ij} .

To facilitate the presentation of the remainder of the model we shall assume without loss of generality that there are only three route attributes: total travel time H_{ijk} , schedule frequency F_{ijk} , and travel cost C_{ijk} . Equation (2.13) now becomes

$$P_{ijk} = K_{ij} [F_{ijk}^{\alpha} / \sum_r F_{ijr}^{\alpha}] [C_{ijk}^{\beta} / \sum_r C_{ijr}^{\beta}] [H_{ijk}^{\gamma} / \sum_r H_{ijr}^{\gamma}] \quad (2.14)$$

where α , β , and γ are the weight placed on each of the attributes.

Combining Eqs. (2.14) and (2.12) give

$$\sum_k P_{ijk} = K_{ij} \sum_k [F_{ijk}^{\alpha} / \sum_r F_{ijr}^{\alpha}] [C_{ijk}^{\beta} / \sum_r C_{ijr}^{\beta}] [H_{ijk}^{\gamma} / \sum_r H_{ijr}^{\gamma}] = 1$$

from which

$$K_{ij} = \frac{\sum_k F_{ijk}^{\alpha} \sum_k C_{ijk}^{\beta} \sum_k H_{ijk}^{\gamma}}{\sum_r F_{ijr}^{\alpha} C_{ijr}^{\beta} H_{ijr}^{\gamma}} \quad (2.15)$$

substituting this value in Eq. (2.14) gives the expression of the choice probability:

$$P_{ijk} = \frac{F_{ijk}^{\alpha} C_{ijk}^{\beta} H_{ijk}^{\gamma}}{\sum_r F_{ijr}^{\alpha} C_{ijr}^{\beta} H_{ijr}^{\gamma}} \quad (2.16)$$

This expression simply states that the probability of an individual choosing a given route for a trip is a function of the values of this route attributes relative to all other available routes. In addition, weights are placed on the attributes to represent their relative importance in the traveller's perception. As these weights are considered to be random variables then the expression of Eq. (2.16) should be restated as a conditional probability of choice given certain values of α , β , and γ . Thus (2.16) is rewritten as

$$P[ijk|\alpha, \beta, \gamma] = F_{ijk}^{\alpha} C_{ijk}^{\beta} H_{ijk}^{\gamma} / \sum_r F_{ijr}^{\alpha} C_{ijr}^{\beta} H_{ijr}^{\gamma} \quad (2.17)$$

where $P[ijk|\alpha, \beta, \gamma]$ is the conditional probability of choosing route k for a journey from i to j given the values of α , β , and γ . In order to find the unconditional choice probability, this expression needs to be integrated over the domains R_1 , R_2 , R_3 of the random variables α , β , and γ respectively. This is given by

$$P[ijk] = \int_{R_1} \int_{R_2} \int_{R_3} P[ijk|\alpha, \beta, \gamma] f(\alpha, \beta, \gamma) d\alpha d\beta d\gamma \quad (2.18)$$

where $f(\alpha, \beta, \gamma)$ is the joint density function of the variables α , β and γ . We shall assume that these weights are assigned by an individual traveller independently of one another. This assumption yields a considerable simplification since it allows the representation of the joint density function as the product of the individual density functions for each weight:

$$f(\alpha, \beta, \gamma) = f_1(\alpha) f_2(\beta) f_3(\gamma) \quad (2.19)$$

These density functions can be estimated by observing individual choices as is described in Chapter 4. The choice model can now be specified in its complete form:

$$P[ijk] = \int_{R_1} \int_{R_2} \int_{R_3} \frac{F_{ijk}^{\alpha} C_{ijk}^{\beta} H_{ijk}^{\gamma}}{\sum_r F_{ijr}^{\alpha} C_{ijr}^{\beta} H_{ijr}^{\gamma}} f_1(\alpha) f_2(\beta) f_3(\gamma) d\alpha d\beta d\gamma \quad (2.20)$$

STOL Demand Model

With both the travel generation model and the choice model completely specified, we proceed now to combine them into a model that will allow the estimation of the potential demand for any route in a corridor. This will also allow the estimation of the demand potential for STOL transport. By combining the value of T_{ij} of the demand for air travel between any two subnodes as obtained from the generation model, with the choice probability P_{ijk} as obtained from the choice model, the expected demand for a route k is:

$$E[T_{ijk}] = T_{ij} P[ijk] \quad (2.21)$$

or

$$E[T_{ijk}] = T_{ij} \int_{R_1} \int_{R_2} \int_{R_3} \frac{F_{ijk}^{\alpha} C_{ijk}^{\beta} H_{ijk}^{\gamma}}{\sum_r F_{ijr}^{\alpha} C_{ijr}^{\beta} H_{ijr}^{\gamma}} f_1(\alpha) f_2(\beta) f_3(\gamma) d\alpha d\beta d\gamma \quad (2.22)$$

If we now denote by ψ the subset of all routes k that are STOL routes then the total demand potential for STOL transportation between any subnode pair i, j , $E[ST_{ij}]$ can be obtained from

$$E[ST_{ij}] = T_{ij} \sum_{k \in \psi} \int_{R_1} \int_{R_2} \int_{R_3} \frac{F_{ijk}^{\alpha} C_{ijk}^{\beta} H_{ijk}^{\gamma}}{\sum_r F_{ijr}^{\alpha} C_{ijr}^{\beta} H_{ijr}^{\gamma}} f_1(\alpha) f_2(\beta) f_3(\gamma) d\alpha d\beta d\gamma \quad (2.23)$$

and the total STOL demand potential in the corridor $E[ST]$ is obtained by adding the demand values for all subnode pairs:

$$E[ST] = \sum_i \sum_j E[ST_{ij}] \quad (2.24)$$

This model allows the estimation of the demand potential for STOL transportation for any STOL service configuration. A given plan for introducing STOL service is represented by the set ψ and by the variables F , C and H for each STOL route. In Chapter 4 the calibration of the model using data from the California Corridor study area is discussed and results of model testing are presented.

CHAPTER 3

DATA BASE AND TRAVEL CHARACTERISTICS

INTRODUCTION

The development of a data base is essential for a study of the demand for transportation. The data base is a collection of information required to provide a basis for formulating and testing hypothesis regarding the determinants of air travel demand and for calibrating models of the demand. This chapter includes a description of the development of the data base for the study, and of some travel characteristics that were observed by studying the information contained in the data base.

DEVELOPMENT OF THE DATA BASE

Types of Data: Two types of data were needed for the development of the data base. One type was the activity data, and the other was the inventory data. The activity data included information on the levels of transportation activity in the study region. For each trip included in the data base the following variables were observed:

- i - trip origin and destination
- ii - airport pair used
- iii - annual frequency of air travel
- iv - travel time, including both access time and line haul time
- v - trip cost
- vi - trip purpose, and land uses at origin and destination

The inventory data included information on the socioeconomic characteristics of the study area and its population, and information describing the air transport system in the study area. The socioeconomic variables included were:

- i - population
- ii - income characteristics
- iii - employment levels,

and the transportation variables included were:

- i - schedule frequencies of service between airport pairs
- ii - line haul travel times between airport pairs
- iii - air fares between airport pairs
- iv - ground access times between population centers and airports

Data Sources: There were numerous sources from which the data included in this study were obtained. The two most important ones were the sources of the travel activity data. These were two travel surveys conducted in the study area. The first survey was conducted in 1970 by the firm Daniel, Mann, Johnson, and Mendenhall (DMJM) as part of a study to develop a "Comprehensive Master Plan of Aviation for the State of California"^[1]. The survey was an on-board origin destination survey covering 32 California airports and eleven participating airlines. It was conducted during a three day period starting Thursday October 8, 1970. A statistical sample including 15,083 usable questionnaire returns was established. This sample represented 28.5 percent of the total number of boarding passengers during the survey

^[1] see reference 25

period.

A major deficiency of this data source was the fact that the survey airports did not include the San Francisco International and Los Angeles International Airport pair. These two airports are by far the two major airports in the State of California and in the Study Corridor. In an attempt to remedy this deficiency, additional travel activity data were obtained from another source. This was the "Survey of Los Angeles International Airport Scheduled Air Passenger Market" done by Landrum & Brown, Airport Consultants^[2]. This survey was also an origin-destination survey but was only limited to the users of Los Angeles International Airport. It was conducted during the week starting Thursday, March 9, 1967, and included 4817 air travellers.

The two surveys were the predominant sources of travel activity information. They provided information on all the activity variables mentioned earlier. In addition to these sources, the 1970 Census Report of the US Bureau of the Census was used to obtain the socio-economic variables of the study area. It was possible to obtain information on total populations, median incomes and employment levels in each of 283 cities in the San Francisco Bay Area and in the Los Angeles Basin.

The transportation characteristics were obtained from yet another set of sources. Schedule frequencies between airport pairs were obtained from the October 1970 Official Airline Guide. In order to account for variation between different days of the week, the frequency

[2] see reference 26

variable was defined as the total weekly schedule frequency of non-stop and one-stop flights. Travel cost information was also obtained from the same source. Coach air fare was used as the sole indication of travel cost. This was due to the lack of additional information on other costs involved in air travel such as access costs. Travel times between origin and destination points were composed of two parts. Line haul air travel times between airport pairs were obtained from the same source: The Official Airline Guide. This means that scheduled travel times, which on the whole are representative of actual times were used. Access travel times between the various cities and the airports in each end of the corridor were obtained from consulting the road maps of the California Automobile Association. Speeds of 25 mph were assumed for city streets; 40 mile for urban highways; and 50 mph for freeways. Terminal times were not included, as they were assumed to be equal for all cases. Naturally, if data on parking constraints at specific airports were available, these would be added to the access travel times.

Data Reduction: It was necessary after the acquisition of the data mentioned in the previous paragraphs to reduce the data files into a form amenable to analysis. The data reduction consisted mainly of constructing computer files that include data records combining the various pieces of information. The Appendix to this chapter describes the detailed contents of the computer files that were constructed.

After the data files were completed it was necessary to do further data reduction for the purpose of the statistical analyses involved in model calibration. This reduction consisted of aggregating the cities in either end of the corridor. It was felt that a total number of 283

cities would constitute a trip table that was too large for efficient analysis, and one where most cells included no trip information.

Therefore, the study area was divided into analysis zones as follows:

The San Francisco Bay Area was divided into 34 analysis zones, and the Los Angeles Basin into 56 analysis zones. The data on the cities within each analysis zone thus obtained were aggregated into single zonal variables.

Final data files were then prepared where the aggregated data were placed randomly thus making the files amenable to statistical analysis. A preliminary analysis was performed on the data thus obtained. In the following section some results of this analysis are described.

SUMMARY OF TRAVEL CHARACTERISTICS

The first step in the analysis of selected travel characteristics was to define the ranges and stratifications for some of the variables. This was done for the following variables, as follows:

1. Trip Purpose: This variable was stratified into three categories which represent an aggregation of a larger number of categories available in the raw data. The categories were:

- work related business
- personal business
- recreation

2. Income: Five classes were defined for this variable. They were defined as follows:

$< 5,000$
5,000 - 9,999
10,000 - 14,999
15,000 - 19,999
 $\geq 20,000$

3. Frequency of Travel: This variable was indicated by the annual number of times a passenger is reported to undertake air travel in the study corridor. The variable was stratified in five categories as follows:

never flown before

1 - 5

6 - 10

11 - 20

> 20

4. Land Use at Trip Ends: Five categories were defined for the land use at the origin and destination of a trip. These were:

Home

Other Residence

Hotel/Motel

Office

Other

The next step was to analyze the variations of each variable within each category and to test, statistically, the significance of the grouping mentioned above. The results of these tests are presented separately for each variable.

Trip Purpose: Work related business was the most predominant trip purpose for air travel in the California Corridor, accounting for slightly over 50 percent of the travellers. Personal business accounted for 15 percent of the travellers surveyed in the DMJM Survey, and about 30 percent of the travellers surveyed in the L&B survey. Recreational travel accounted for about 30 percent of the travellers included in the DMJM survey and less than 10 percent of those included in the L&B

survey. These results are shown graphically in Fig. 3-1. The disparity between the two samples is probably due to the difference in the time frame of the two surveys. The L&B survey had a duration of one whole week and whereas the DMJM survey had a duration of three days starting on a Thursday. It is likely therefore that a bias toward weekend travel is present in the DMJM survey sample. This may explain the larger proportion of recreational travel.

For the purpose of model calibration in this study it was decided in view of the above results to further aggregate trip purposes into two categories: business (standing for work-related business) and non-business, including both personal business and recreational travel. In order to justify the need for including trip purpose in the analysis, a statistical Chi-square test was performed to compare trip making frequencies by trip purpose. It was found, as expected, that trip making frequencies for different trip purposes were significantly different. On the basis of this it was then decided that separate demand models should be calibrated for each of the two trip purpose categories: business, and non-business.

Family Income: As might be expected in advance, the majority of travellers in the corridor belonged to a high income group. Over 34 percent for all travellers had an annual family income in excess of \$20,000. Only 9 percent of the travellers had an income under \$5,000. This difference was even more distinct in the case of business travellers taken alone. 53 percent of the business travellers had an annual income in excess of \$20,000 and only 0.5 percent under \$5,000. The income distributions of the total survey samples are shown in Fig. 3-2.

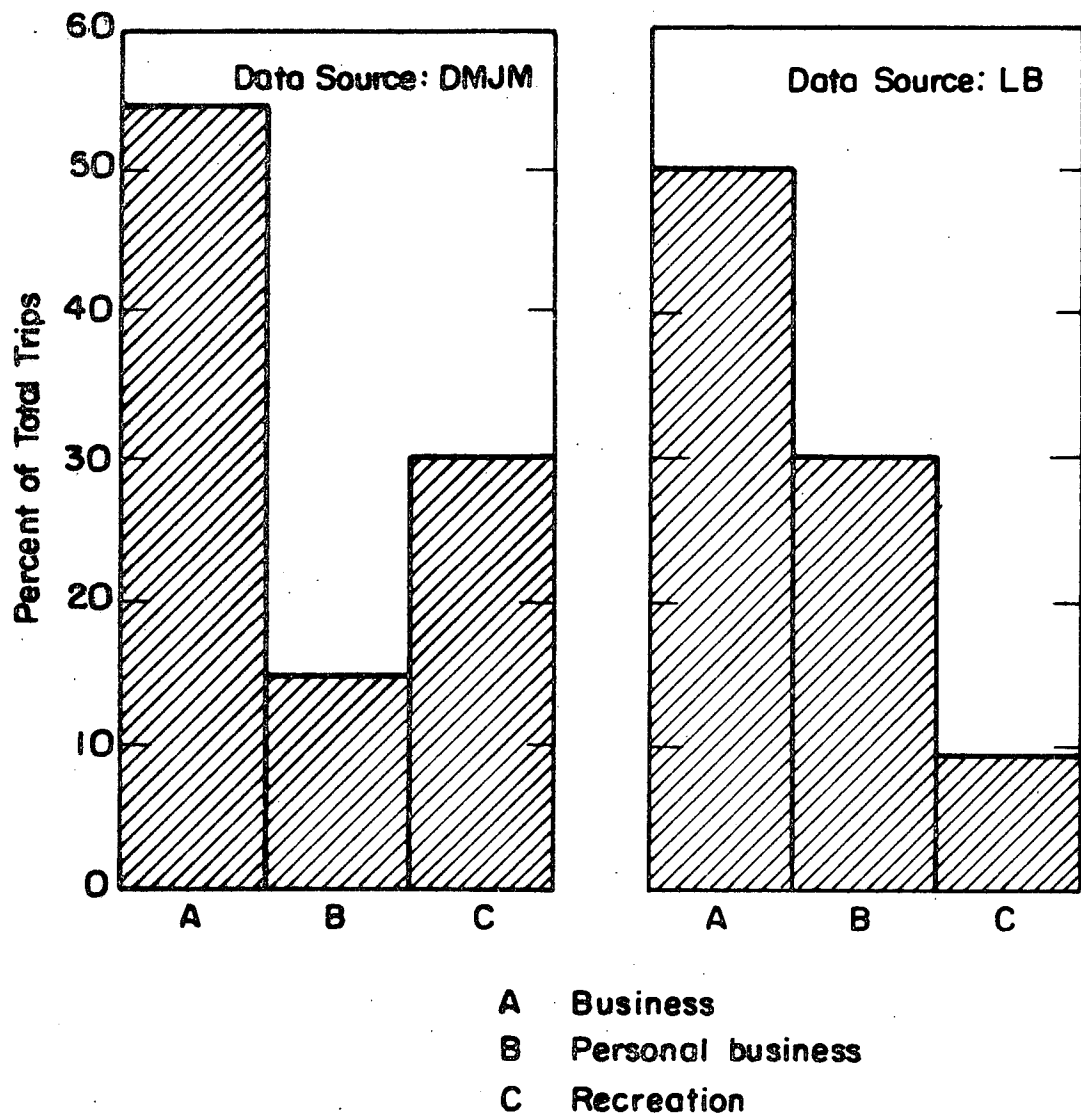


Figure 3-1 Trip Purpose Distribution

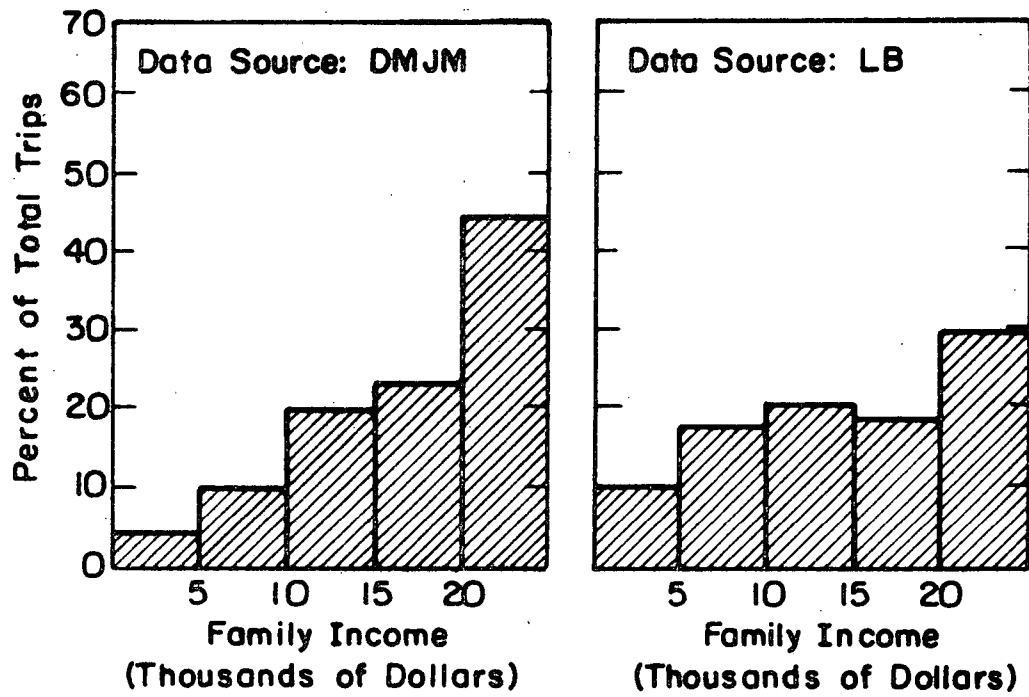


Figure 3-2 Income Distribution of Business Travelers

Trip Frequency: The most predominant frequency of air travel category in the corridor was the 1-5 category, accounting for 35 percent of all travellers. Trip frequency, however, was found to vary significantly with income for business travellers but not for non-business travellers. A Chi-square test showed that annual frequencies for different income groups of business travellers were significantly different, but not so for non-business travellers. In particular it was found that business travel frequency increased with the annual income of the travellers. A regression analysis was performed to study the relationship further. The results, summarized in Table 3-1 and Fig. 3-3 show a significant relationship between the two variables. As shown in Table 3-1 it seems that a nonlinear model of the form shown is a reliable estimator of the relationship between income and trip making. As is described in Chapter 4, the income variable was successfully used in calibrating travel generation models.

Land Use At Trip Ends: The interest in this trip descriptor stems from the interest in assessing the locations of major air travel generation points within an urban area. This knowledge is needed for the evaluation of potential locations for STOL and other short haul airports.

The most predominant type of trip origin was the traveller's home. The proportions of travellers originating at home were 51 percent for business travellers, 67 percent for personal business, and 73 percent for recreational travellers. At the same time, 33% of business travellers, 22% of personal business travellers, and 15% of recreation travellers ended their trips at home. Figure 3-4 shows the trip end

TABLE 3-1 — RESULTS OF REGRESSION ANALYSIS ON
TRIP FREQUENCY AND FAMILY INCOME

Function	Data Source	α	β	R^2	F - statistics
$Y = \alpha X$	DMJM	.464	-	.6488	(α) 10.03
	L & B	.671	-	.6473	(α) 8.76
$Y = \alpha X^\beta$	DMJM	1.70	.58	.9800	(α) 4.66 (β) 14.06
	L & B	2.58	.60	.9705	(α) 5.39 (β) 9.94

Y = Annual Trip Frequency

X = Annual Family Income

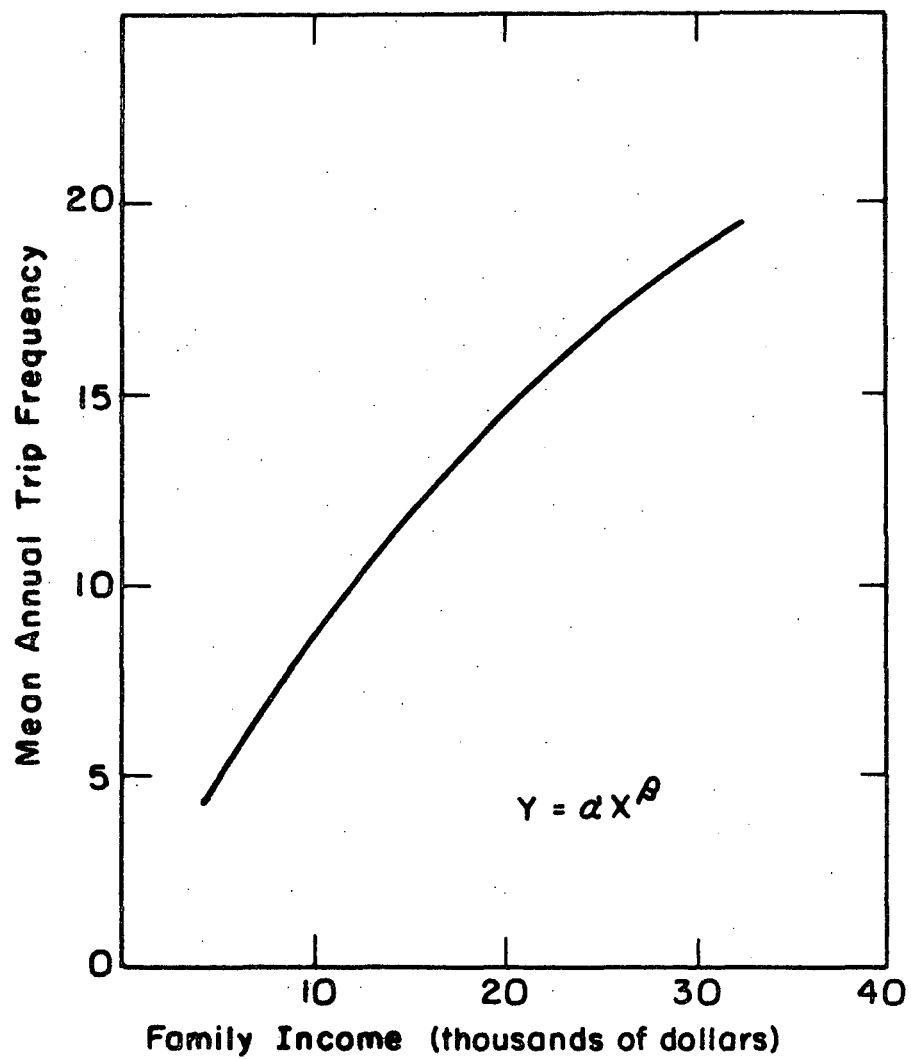


Figure 3-3 Income-Trip Frequency Relationship for Business Travelers

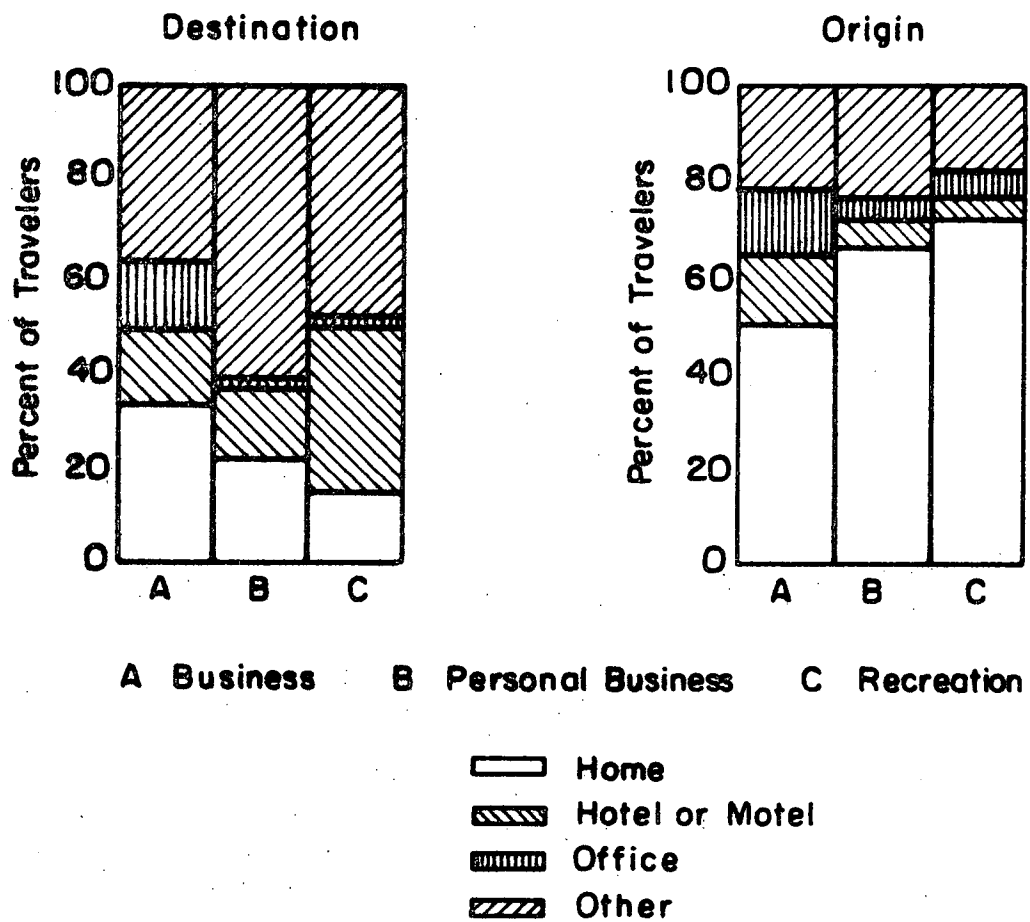


Figure 3-4 Trip End Distribution of Travelers

distributions of travellers by trip purposes.

It was also observed that the proportion of travellers originating at their home increases as their income increases. This result, shown in Fig. 3-5 was confirmed with a statistical Chi-square test.

The importance of the place of residence as a generation point of air travel should then be expected to increase, as the general income levels of travellers increase. Potential STOL-port site locations will necessarily have to be influenced by the locations of residences as well as places of work.

Access Travel Time: More than 70 percent of all travellers originated and terminated their trips at locations less than 30 minutes from the airports used, and fewer than 5 percent incurred access travel times in excess of 60 minutes. Origin and destination access travel time distributions are shown in Figs. 3-6 and 3-7 respectively. The distributions show the predominance of short travel times, as well as similarity across trip purpose categories.

It seems from these results that the study area, the San Francisco-Los Angeles Corridor, does not represent an area with severe airport access problems. This does cast a certain bias on the results of the model calibration, leading to the underestimation of the importance of ground access times in trip making.

Ground Travel Mode: A variable related to access travel time is the ground travel mode. Data in the survey files were summarized and showed the anticipated result that the private automobile was the predominant access mode, with 43 percent of all travellers driving to their departure airport and 35 percent of them arriving at their departure

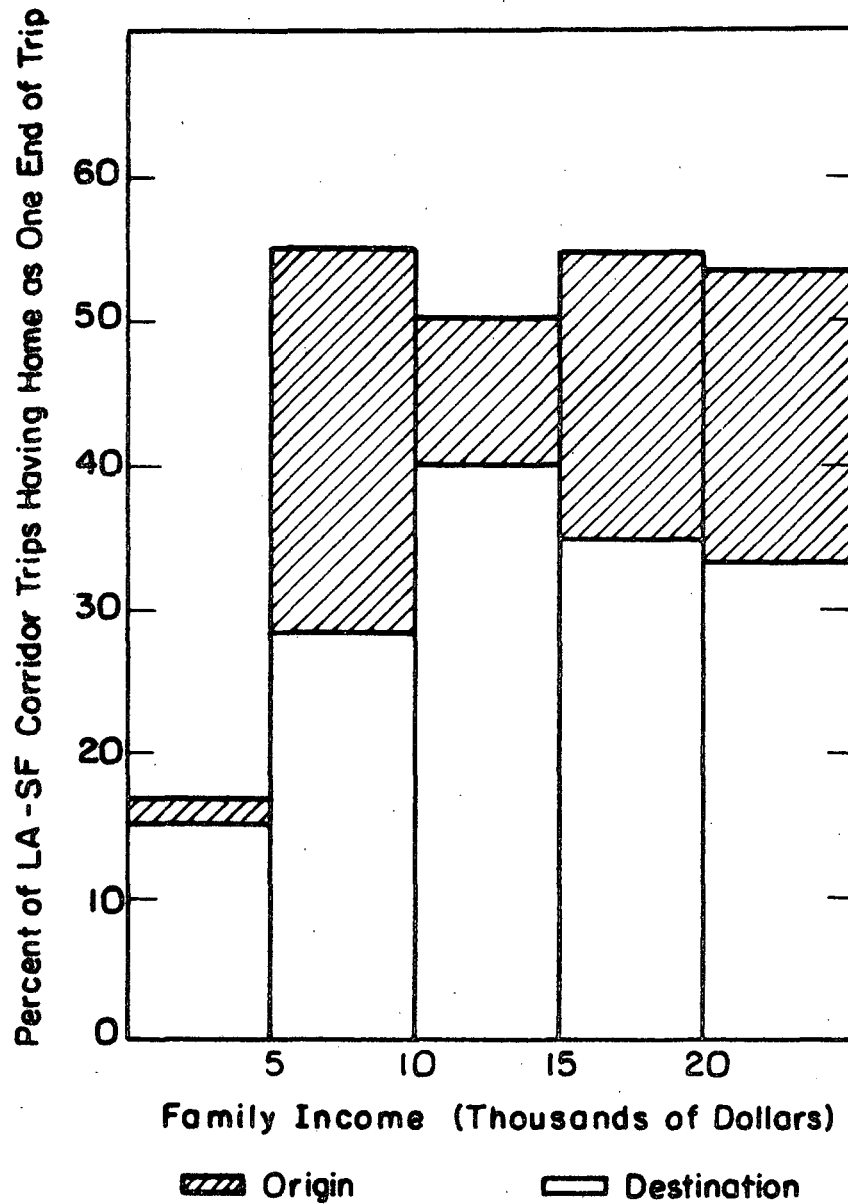


Figure 3-5 Income Distribution of Home-Based Travelers

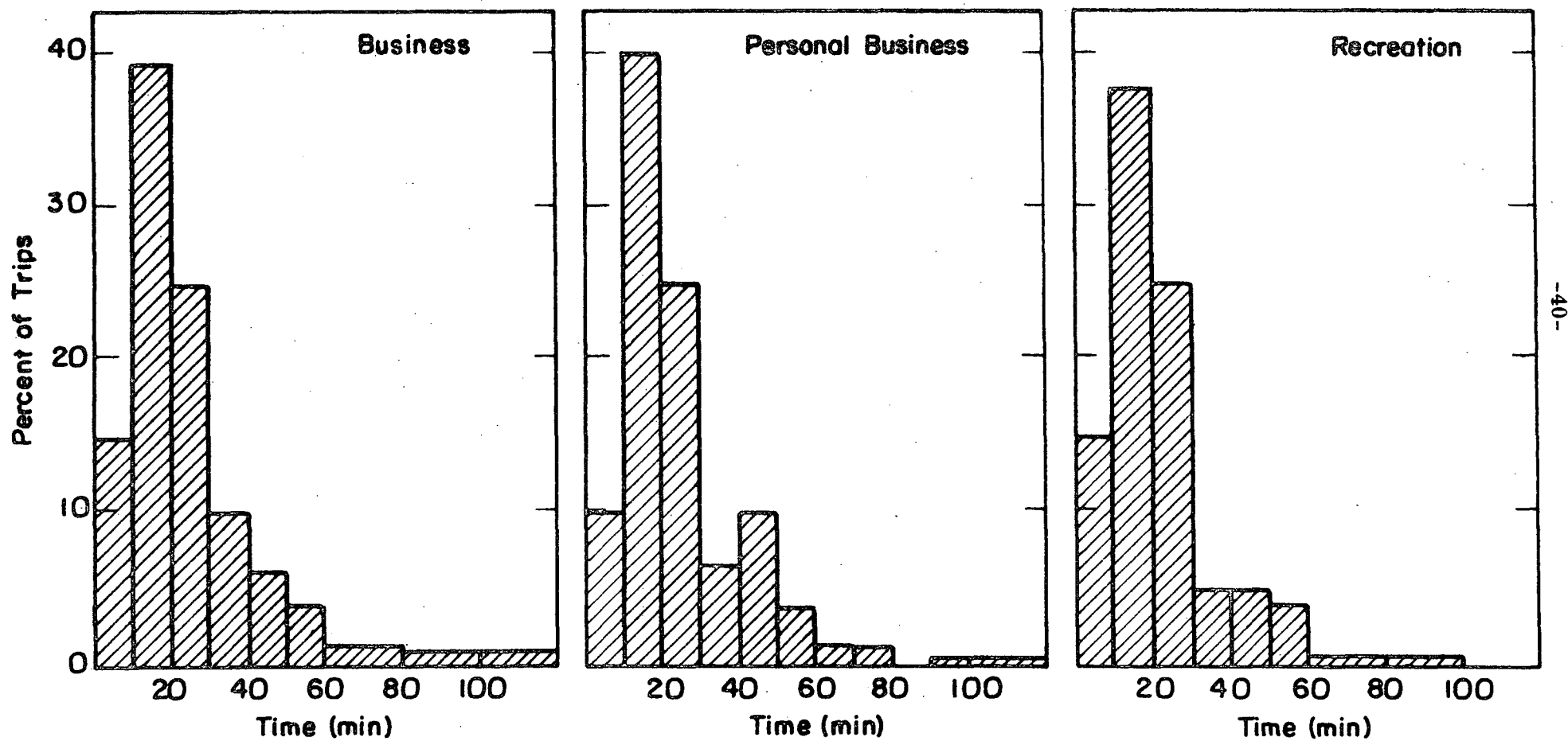


Figure 3-6 Origin Access Trip Length Distribution

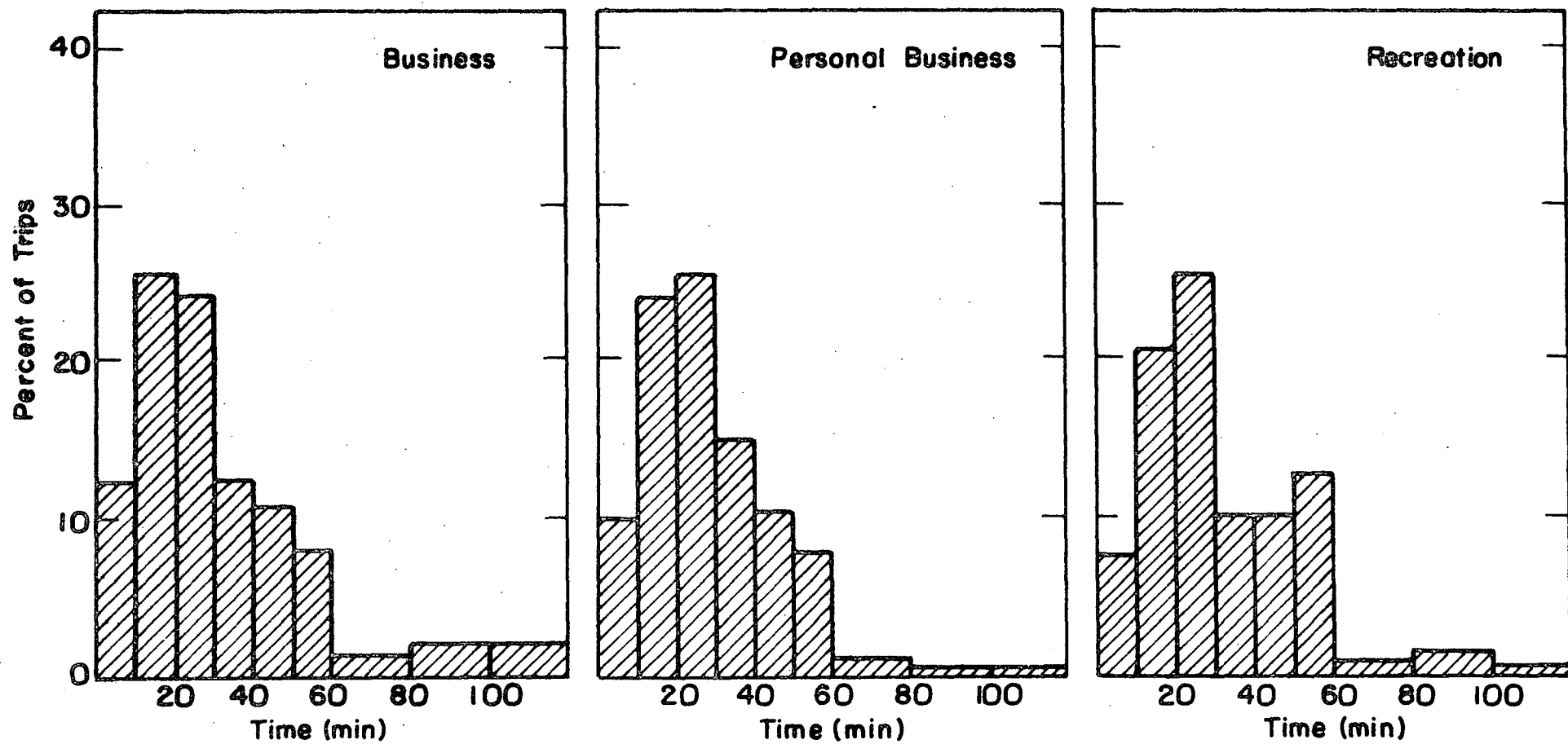


Figure 3-7 Destination Access Trip Length Distribution

airport as automobile passenger. At the destination airport, 35 percent of all travellers leave as automobile passengers and slightly under 20 percent drive to their destination. The mode distributions are shown in Fig. 3-8. Upon comparing access mode characteristics with income characteristics it was found that the use of the automobile increases slightly with increasing income. On the other hand it was found that access modes did not vary significantly as ground travel times changed.

SUMMARY

The data base developed for this study included two major types of information: activity information and inventory information. The activity information was derived from the results of two travel surveys. The first was conducted in October 1970, and included all airport pairs in the California Corridor with the exception of the San Francisco-Los Angeles Airport pair. The second survey was conducted in March 1967, and at Los Angeles International Airport. The inventory data were obtained from a variety of published sources including the US Census Report and the 1970 Official Airline Guide.

In the data base used, it was not possible to avoid some major deficiencies and sources of bias. The exclusion of the San Francisco-Los Angeles Airport pair from the 1970 survey presented a problem, particularly since this survey provided the major source of travel activity information. The results of the 1967 survey were limited to Los Angeles International, thus partially completing and fulfilling the originally required data. However, it was found that the mixed use of data sources that referred to different years, and that were conducted at different times of the year presented some conceptual

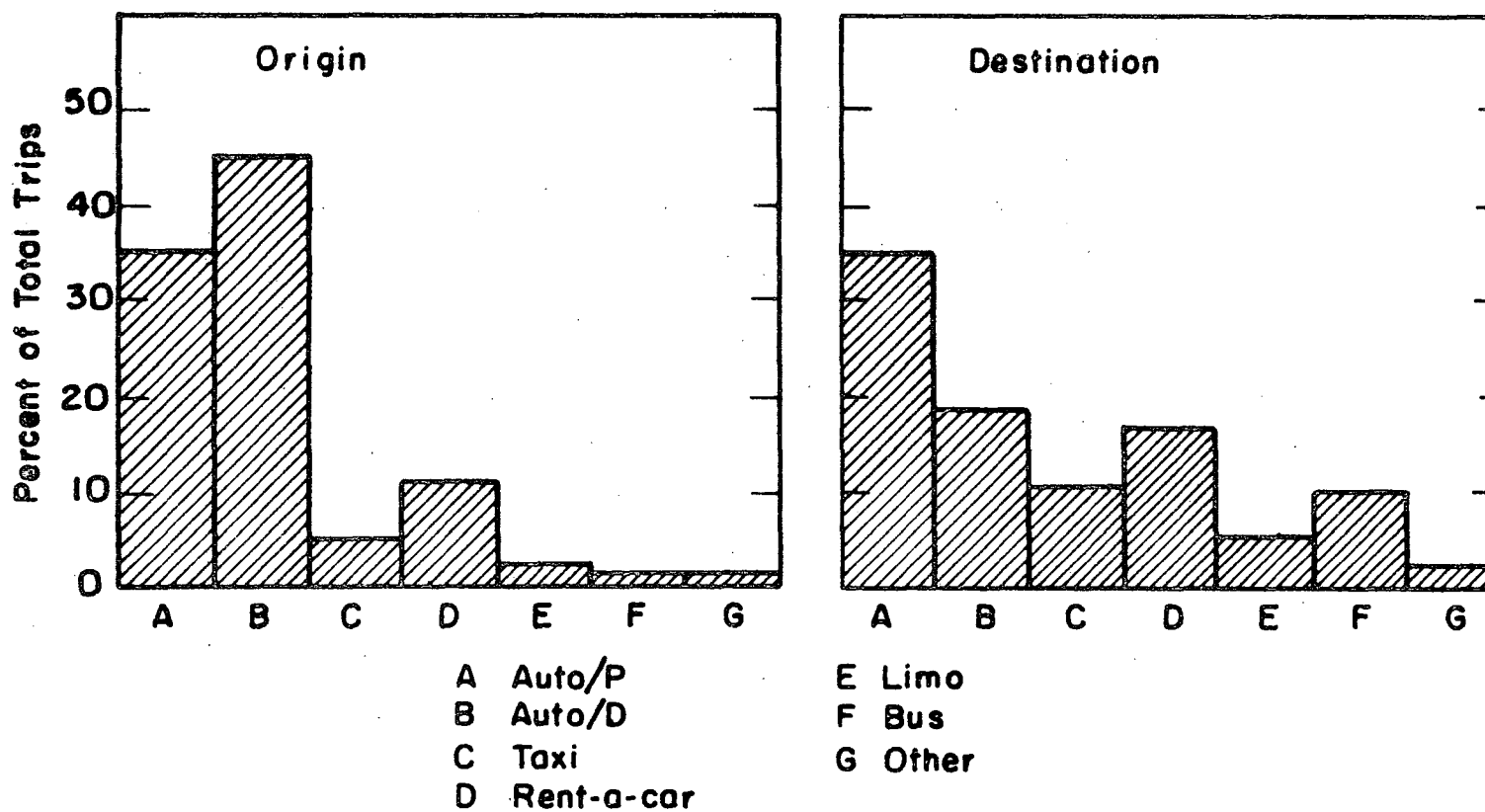


Figure 3-8 Ground Transportation Mode Distribution

problems. It was decided to use only the results of the 1970 survey for the calibration of the demand models. In this manner, it was believed, a consistent data set would be used in spite of the fact that some major portion of the corridor travel was not included. It was argued that there is no inherent reason why the users of the San Francisco-Los Angeles Airport pair should have a route choice process that is different from that of the users of the other airports in the corridor.

Finally, a summary of travel characteristics showed that income was an important determinant of trip making. It also showed that separate models should be constructed for business and non-business travellers. Ground travel time did not appear to be a major deterrent to airport access in the study area.

CHAPTER 4

MODEL CALIBRATION AND TESTING

Introduction

Using the data described in the previous chapter, the two models used in this study were calibrated and statistically tested. Model calibration involves estimating parameter values that need to be known to make a model operational. Statistical testing, on the other hand is the process of comparing model results with the original data. In other words, it is the process of testing the ability of calibrated model to reproduce the data upon which it was calibrated. This type of model validation is necessary, but not sufficient for a forecasting model. There is no sufficient test for the validity of a forecasting model. A number of model evaluation criteria are used to judge calibrated models. These are discussed in this chapter. The calibration and testing procedures used, as well as their results are also described in this chapter. The numerical and statistical analysis techniques used are exposed briefly, but detailed discussions of them are presented in an Appendix to this chapter. This chapter is divided into two main parts. One part deals with the calibration and testing of the travel generation model, and the other with the choice model.

Travel Generation Model

The travel generation model was calibrated using techniques of multiple regression analysis and least squares estimation. As mentioned earlier, the model, because of its logarithmic nature is quite amenable to this type of calibration. At the outset of the analysis

a set of criteria was defined. These are used in evaluating the calibration results. In general, mathematical models do not describe precisely the travel patterns used to calibrate them. This is, in part, due to the inherent randomness of the real world, a randomness which is not easy to reproduce in linear regression models. It is necessary, however, to determine whether a particular fit, or calibration is acceptable; whether it requires additional improvements through further analysis' or whether it should be rejected as fundamentally incapable of simulating the real world as it was intended to do. It is difficult to set forth rigorous evaluation criteria. Frequently the evaluation is performed in relative rather than absolute terms; that is, the question is often one of choosing a model from among alternatives. Aided by a number of statistical rules, the evaluation of a model calibration is largely qualitative. In this sense it is guided by considerations such as the costs involved in further analysis; the availability of reliable data; and, perhaps most important, the purposes for which the models are used.

The following criteria were used to evaluate the multiple regression calibration results of the models:

1. Consistency with a priori parameter characteristics. In many cases transportation demand models usually contain variables such as population and income or transportation variables such as travel time and cost. The elasticity of transport demand for some of these variables is often specified a priori on the basis of common sense and knowledge of travel behavior. For example, it is expected that as the income of a subset of the population increases their travel generation

will likewise increase. It is also expected that as the cost of a given trip increases, the number of people undertaking such a trip decreases. Therefore, knowledge of the signs of some of the parameters is specified in advance. A criterion to judge a least squares calibration is then, whether the estimated parameters have signs, or values as expected.

2. Statistical Significance Tests: Here a number of tests are used to test the significance of the relationships obtained by regression analysis. The coefficient of multiple determination R^2 indicates the proportion of the total variations in the dependent variable that are explained by the calibrated model. Test statistics such as the F-statistic or the t-statistic indicate the significance of the relationship between the dependent variable and any, or all, of the independent variables included in the model. Finally, estimates of the standard error of the estimate of the dependent variable are also used to judge the confidence in the results obtained from the model. Together, all these tests, when performed, give the analyst a considerable amount of quantitative input to aid in judging the validity of a calibrated model.

For the calibration of the travel generation model the study corridor was divided into 34 zones in the San Francisco Bay Area, and 56 in the Los Angeles Basin. 1970 air travel volumes between the zone pairs were obtained. Out of the 1904 zone pairs obtained by combining the 34 zones at one end of the corridor with the 56 zones at the other end, only 317 pairs had sufficient volumes of traffic between them that could be used in the calibration. From available

census information on all these cities, 1970 populations, income and employment figures were obtained.

In order to perform the multiple regression analysis, it was necessary to transform the travel generation models described in Eqs. (2.2) - (2.4) of Chapter 2 from their multiplicative form into a linear form. This was easily done by using the logarithmic transformations. The models were thus transformed to:

$$\ln T_{ij} = \alpha_0 + \alpha_1 \ln P_i + \alpha_2 \ln P_j + \alpha_3 \ln Y_i + \alpha_4 \ln Y_j + \alpha_5 \ln t_{ij} \quad (4.1)$$

$$\ln T_{ij} = \alpha_0 + \alpha_1 \ln P_i + \alpha_2 \ln P_j + \alpha_3 \ln Y_{ij} + \alpha_4 \ln t_{ij} \quad (4.2)$$

$$\ln T_{ij} = \alpha_0 + \alpha_1 \ln P_i + \alpha_2 \ln P_j + \alpha_3 \ln Y_{ij} + \alpha_4 \ln LS_{ij} \quad (4.3)$$

The results of regressions performed on these models are shown in table 4-1, from which some interesting observations can be made.

1. In all regressions except one, population seemed to be a variable highly significant in explaining total travel generations. The positive signs of the populations variables were as expected.

2. In all regressions median income also was a significant variable. The income elasticities of travel demand were, as expected, positive. This means an increase in number of trips is associated with an increase in income.

3. Shortest travel time t_{ij} did not seem to be as highly significant as the other variables, even though the parameters associated with it were all negative, as expected. This is probably due to the fact that there is very little variations in this variable among the zone pairs in the study corridor.

TABLE 4.1 — RESULTS OF REGRESSIONS ON BUSINESS TRIPS

Variables	Models						
	1	2	3	4	5	6	7
Constant	-10.67	- 6.2	- 7.97	- 4.39	- 2.58	- 7.32	-13.44
$\ln P_i$	.30 (2.19)*	.31 (36.88)	.29 (32.98)	.31 (34.46)	.29 (32.12)	.29 (32.62)	.30 (35.62)
$\ln P_j$	- .32 (3.83)	.31 (36.00)	.37 (63.22)	.34 (62.99)	.31 (63.71)	.37 (61.23)	.40 (99.57)
$\ln Y_i$	1.04 (12.40)	1.02 (11.60)					
$\ln Y_j$	.19 (.38)	- .12 (.15)					
$\ln Y_{ij}^{**}$			.48 (4.70)	.63 (2.23)		.89 (4.20)	1.10 (7.50)
$\ln t_{ij}$	- .28 (1.11)	- .46 (3.24)	- .32 (1.54)	- .41 (2.72)	- .53 (4.89)	- .33 (1.70)	
$\ln E_i$	.02 (.01)						
$\ln E_j$	.70 (16.70)						
$\ln LS_{ij}$							.31 (.99)
R^2	.3624	.3279	.3128	.3074	.3024	.3117	.3101

* Numbers in parenthesis represent F - statistics.

**In Model 3, $Y_{ij} = Y_i \cdot Y_j$. In Model 4, $Y_{ij} = (P_i \cdot Y_i + P_j \cdot Y_j)/(P_i + P_j)$. In Models 6 & 7, $Y_{ij} = (Y_i + Y_j)/2$.

4. In all models tested the total explanatory power was rather low. R^2 -values for all the models fall in the range 0.30-0.40. Since the explanatory power of the variables included in the models seemed sufficiently high as explained earlier, this indicated that there are some additional explanatory variables which should have been included in these models. It seems likely that additional variables that describe the socio-economic nature of the various cities in the corridor should be included. Cities should also have been grouped with respect to their airport access characteristics. This last grouping was performed in the process of calibrating the choice model and good results were obtained as will be discussed later in this chapter.

5. Based mainly on the results described in the preceding paragraph it was concluded that the models as calibrated were not suitable for the forecasting of travel demand. With the R^2 -values obtained being as low as they were, further testing was hardly necessary to justify this conclusion. On the other hand, the explanatory power of the variables included in the model seemed sufficiently high, as described earlier, to warrant use of the models. With the demand elasticities to variables such as population and income being estimated with sufficiently high confidence it should be possible to use them in relating changes in income and population to changes in travel generation. This is described below.

Let us re-consider the general structure of the travel generation model:

$$T_{ij} = \prod_k X_k^{\alpha_k} \quad (4.4)$$

from which it is clear that α_k is the elasticity of the travel demand with respect to variable X_k . The elasticity is the ratio of relative changes of T and X, and is given by:

$$\alpha_k = \frac{\partial T_{ij}/T_{ij}}{\partial X_k/X_k}, \quad \text{for all } k \quad (4.5)$$

The total relative change in T_{ij} that is brought about by changes in the respective variables X_k can be calculated from the equation for the total derivative as follows:

$$dT_{ij} = \sum_k \frac{\partial T_{ij}}{\partial X_k} dX_k \quad (4.6)$$

from which

$$\frac{dT_{ij}}{T_{ij}} = \sum_k \alpha_k \frac{dX_k}{X_k} \quad (4.7)$$

For example, from model 6 in Table 4-1 it can be seen that the elasticity of travel with respect to population has a value of 0.29 and, with respect to income a value of 0.89. Thus a 10 percent increase in population of the origin city will cause a 2.9 percent increase in travel generation, and a 10 percent increase in the average median income of the city pair will cause an 8.9 percent increase in travel generation. If both these increases occur simultaneously then the total increase in travel generation will be as given in Eq. (4.7) above;

$$\begin{aligned}\frac{dT_{ij}}{T_{ij}} &= .29 \frac{dP_i}{P_i} + 0.89 \frac{dY_{ij}}{Y_{ij}} \\ &= .29 \times 10.0\% + 0.89 \times 10.0\% \\ &= 11.8\end{aligned}$$

The models for non-business travel were calibrated in the same way as those for business travel. The results of the regression analyses on these models are shown in Table 4-2, from which conclusions very similar to the ones already drawn appear in order with one exception. It is seen from looking at the F-values of the travel time variables that they are quite low in all the models. This means that this variable has a low explanatory power and is not significantly related to travel generation. This result seems intuitively appealing since it is reasonable to deduce that non-business travellers, who are mainly recreational travellers, are not sensitive to travel time at least for short haul travel.

As in the case of business travel models, absolute predictions are not possible with the non-business models. However, since the elasticities of some of the explanatory variables are highly significant, they are used in relating relative changes in these explanatory variables to relative change in travel generation. The forecasts of the total travel demand in the corridor is therefore presented in Chapter 5 in a parametric manner rather than in an absolute manner.

The Choice Model

The calibration of the choice model involved a process more complex than that involved in the calibration of the travel generation model. This is due to the fact that the choice model is of a stochastic nature,

TABLE 4-2 — RESULTS OF REGRESSIONS ON NON-BUSINESS TRIPS

Variables	Models			
	1	2	3	4
Constant	-20.66	-16.10	-15.65	-15.65
$\ln P_i$	-.35 (1.90)*	.32 (23.88)	.31 (22.67)	.31 (22.67)
$\ln P_j$	-.37 (4.10)	.40 (42.42)	.42 (56.94)	.42 (56.94)
$\ln Y_i$	1.03 (7.44)	1.05 (7.10)		
$\ln Y_j$	.84 (5.39)	.45 1.49		
$\ln Y_{ij}^{**}$			1.40 (7.37)	1.40 (7.37)
$\ln t_{ij}$	-.52 (2.86)	.18 (.32)	.24 (.63)	
$\ln E_i$	.66 (7.95)			
$\ln E_j$	.86 (21.13)			
R^2	.3358	.2619	.3576	.3558

* Numbers in parenthesis represent F - statistics

** $Y_{ij} = (Y_i + Y_j)/2.0$

and has a more complex mathematical structure. There were three major steps involved in the calibration of the choice model. These were:

(i) The derivation of estimates (from observed data) of the weight α , β , and γ for the variables departure frequency, travel cost and travel time, respectively.

(ii) The statistical estimation of the distribution functions of the weight α , β , and γ .

(iii) The numerical solution of the model as described in Eq. (2.20) of Chapter 2.

The procedure followed to calibrate the choice model involved subsetting of the data available into a number of randomly selected groups. For each group, estimates of each of the parameters α , β , and γ were obtained.

The general formulation of the choice model as shown in Eq. (2.20) in Chapter 2, is as follows:

$$P[ijk] = \int_{R_1} \int_{R_2} \int_{R_3} \frac{F_{ijk}^{\alpha} C_{ijk}^{\beta} H_{ijk}^{\gamma}}{\sum_r F_{ijr}^{\alpha} C_{ijr}^{\beta} H_{ijr}^{\gamma}} f_1(\alpha) f_2(\beta) f_3(\gamma) d\alpha d\beta d\gamma \quad (4.8)$$

In order to determine the probabilities $P[ijk]$ it was first necessary to estimate the distribution functions $f_1(\alpha)$, $f_2(\beta)$, and $f_3(\gamma)$. To do this the data was divided into groups that were randomly selected. For each such group estimates of α , β , and γ were obtained as the elasticities of a function:

$$T_{ijk} = F_{ijk}^{\alpha} C_{ijk}^{\beta} H_{ijk}^{\gamma} \quad (4.9)$$

The estimation procedure was repeated for each group and this produced a number of readings of α , β , and γ which were analogous to randomly selected observations on three random variables. These readings were then used to estimate the distribution functions $f_1(\alpha)$, $f_2(\beta)$, and $f_3(\gamma)$. Once these distribution functions were estimated, the solution of the model in (4.8) was carried out by performing the three-dimensional integration and estimating the values of $P[ijk]$. It should be noted that a numerical analysis technique had to be used to solve the model of (4.8) since it was not possible to perform an analytical integration. A detailed description of this calibration process is presented below.

As indicated in the previous chapter, the travel data contained 1637 business trip records and 1467 non-business trip records of air trips in the study corridor. This trip information was collected on 12 CTOL routes in the corridor which are:

1. Oakland - Hollywood/Burbank
2. Oakland - Los Angeles International
3. Oakland - Ontario
4. Oakland - Santa Ana (Orange County)
5. San Francisco International - Hollywood/Burbank
6. San Francisco International - Long Beach
7. San Francisco International - Ontario
8. San Francisco International - Santa Ana
9. San Jose - Hollywood/Burbank
10. San Jose - Los Angeles International
11. San Jose - Ontario
12. San Jose - Santa Ana

As noted earlier these routes do not include the San Francisco International-Los Angeles International route for which survey data were not available. This of course reduces the accuracy of the estimation based on the remaining routes since it is known that San Francisco International and Los Angeles International are by far the most important

two airports in the corridor. However, since the calibration technique uses a group of travel records randomly selected from the trip file, it can be said that the loss of accuracy in the analysis is only to the extent that the sample used may be considered biased.

A certain amount of data aggregation was necessary in order to estimate the parameters of the model. The purpose of this aggregation was to provide within each data group a sufficient number of trip records to allow the estimation of α , β , and γ . The San Francisco Bay area zones were aggregated into 7 and the Los Angeles Basin zones into 8 super zones. Figures 4-1 and 4-2 show maps indicating the two metropolitan areas in the corridor and the corresponding zones in each. The aggregation yielded a 7 by 8 trip table and was done at the expense of accuracy, particularly in determining access times between trip ends and airports. Ideally, one would like to have rather small zones so that access times can be determined accurately. However, with small zones a large trip table results and many cells would contain numbers too small to allow reliable statistical estimation. A check of access times was performed on the large zones shown in Figs. 4-1 and 4-2 and it was found that in no cases would the error exceed 10 minutes. This was thought satisfactory for the purposes of this analysis.

The next step was to divide the records into groups. This was done with the aid of a computer program called SCRAM*. This program first

* This and all other computer programs used in this study are documented in details in a special Appendix.

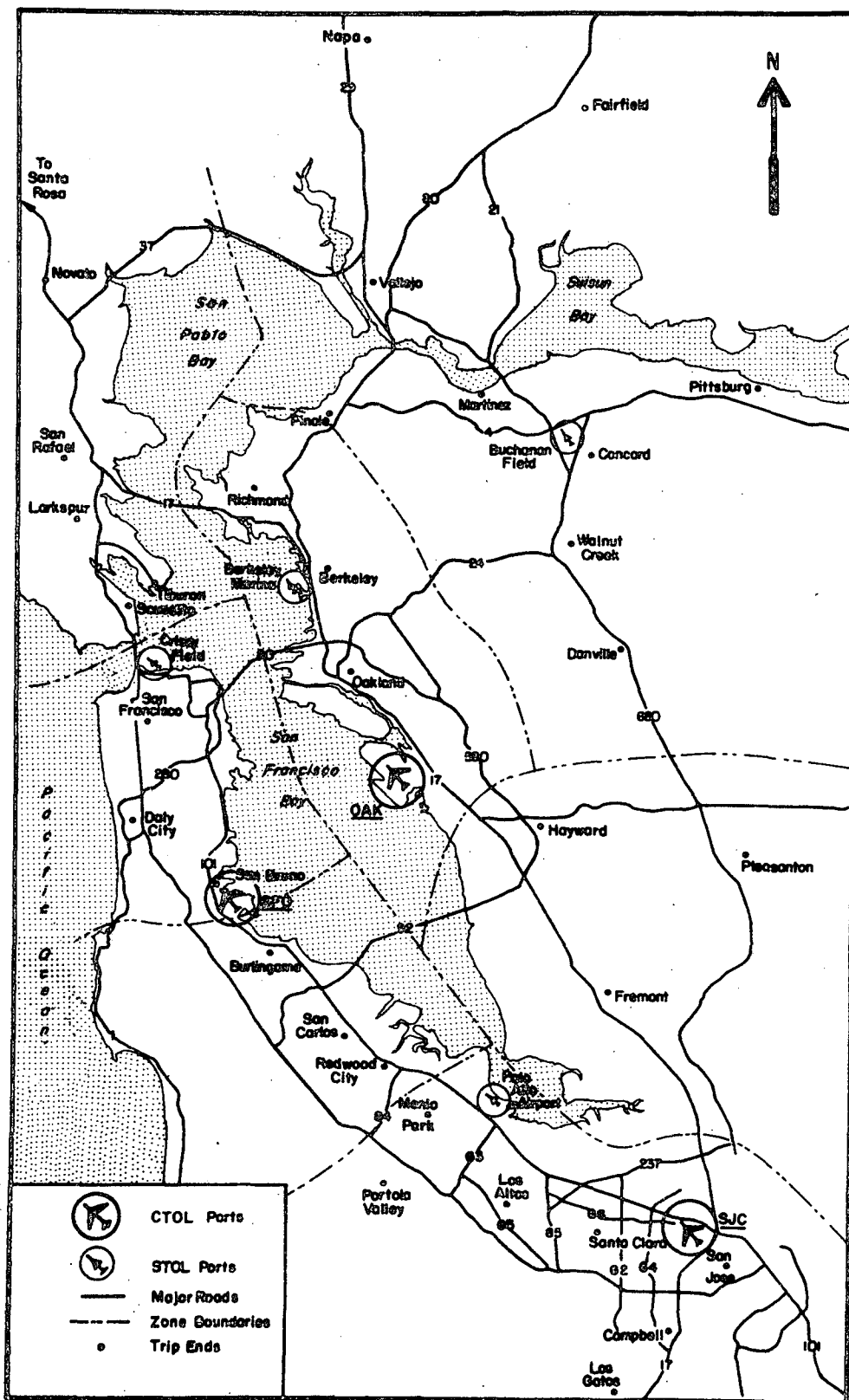


Figure 4-1 San Francisco Bay Area And The Corresponding Zones

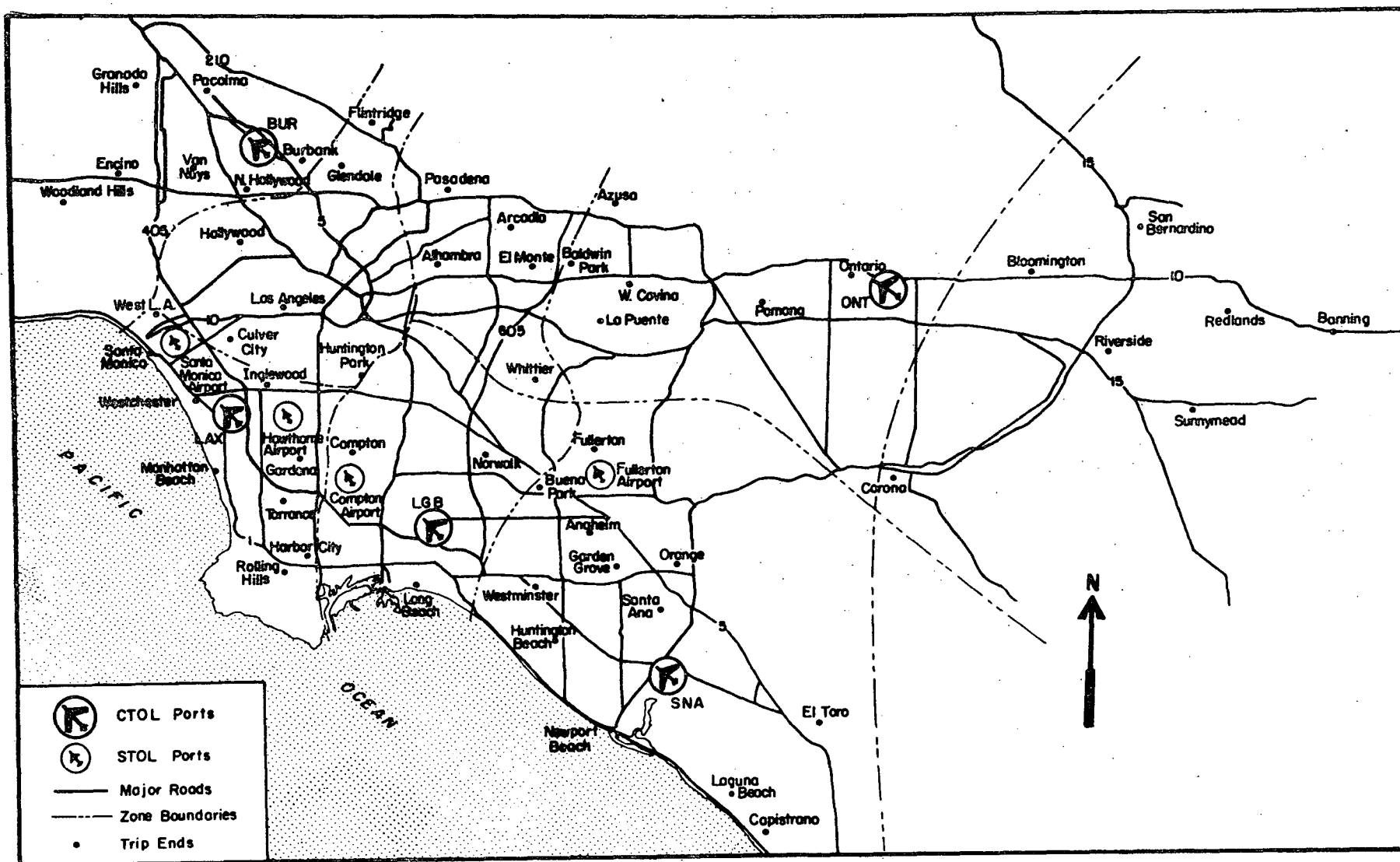


Figure 4-2 Los Angeles Basin And The Corresponding Zones

"scrambled" the records on the file to assure random selection of groups and then subdivided into 33 random groups, and the non-business trip data into 30 random groups. Within each group approximately equal sample sizes were maintained. The data was then sorted and prepared for further analysis with the help of another computer program called PREBMD.

The next step was to estimate for each group the values of α , β , and γ . This was done by specifying intermediate models where these parameters were denoted as elasticities. It should be clear (from the model as shown in Eq. (4.9)) that α , β , and γ are indeed elasticities with respect to departure frequency, travel cost and travel time respectively. In specifying the value of the explanatory variables air fare was considered the proxy for total travel cost. It would have been desirable to include access travel costs, if data were available. Travel time was separated into its two major components: access time and line haul travel time. Again it would have been desirable to include processing times at the respective airports to account for the effect of terminal congestion on the choice process. But data on these were also not available. The following alternative forms of the intermediate models were tested:

$$\text{i- } T_{ijk} = F_{ijk}^{\alpha} C_{ijk}^{\beta} (TTT)_{ijk}^{\gamma} \quad (4.10)$$

$$\text{ii- } T_{ijk} = F_{ijk}^{\alpha} C_{ijk}^{\beta} (ACT)_{ijk}^{\gamma} \quad (4.11)$$

$$\text{iii- } T_{ijk} = F_{ijk}^{\alpha} C_{ijk}^{\beta} (ACT)_{ijk}^{\gamma_1} (LHT)_k^{\gamma_2} \quad (4.12)$$

where $(TTT)_{ijk}$ is the total travel time between i and j by route k,
 $(ACT)_{ijk}$ is the access time at both ends of the trip between
i and j, by route k, and
 $(LHT)_k$ is the line haul travel time on route k.

Stepwise linear regression was performed on the linearized forms of the models of Eqs. (4.10) - (4.12). Similarly to what was found earlier in the calibration of the travel generation model, line haul travel time was not found to be significant as an explanatory variable. Again this is probably due to the lack of variations in line haul travel times among the 12 routes considered. The model of Eq. (4.11) was therefore selected and used for estimating the values of α , β , and γ .

For the business trips, 33 estimates of α , 30 of β , and 29 of γ were obtained. The differences were due to the fact that for some of the 33 groups some variables showed insignificant coefficients and no estimates were obtained. Table 4-3 shows the estimated values for the three parameters as obtained by least squares estimation. From the table some of the validity checks can be performed by inspection. First, it can be seen that α is positive in all cases which is expected, since α is the demand elasticity with respect to frequency of service. The parameter β on the other hand is negative in all cases which is also expected, since β represents the demand elasticity with respect to travel cost. The parameter γ does not seem to have a consistent sign. But a look at the results of the least squares estimation indicates that in all cases, the travel time variable did not possess

TABLE 4-3 ELASTICITY ESTIMATES OF ROUTE CHARACTERISTICS FOR
BUSINESS TRAVEL (F-STATISTICS SHOWN IN PARENTHESIS)

SAMPLE NUMBER	DEPARTURE FREQUENCY ELASTICITY	TRAVEL COST ELASTICITY	ACCESS TIME ELASTICITY	R ²	STANDARD ERROR
1	.769 (35.2)	-.425 (5.0)	-.023 (.04)	.9581	.3560
2	.676 (70.4)	-.344 (5.8)	.010 (.01)	.9727	.2931
3	.421 (24.6)	---	-.031 (.08)	.9743	.2997
4	.642 (53.5)	-.351 (6.6)	.030 (.11)	.9733	.2721
5	.638 (95.5)	-.287 (6.0)	-.021 (.07)	.9824	.2205
6	.696 (60.8)	-.517 (15.6)	.107 (1.67)	.9735	.2735
7	.586 (65.8)	-.439 (13.6)	.152 (3.72)	.9794	.2396
8	.541 (38.0)	---	-.118 (1.68)	.9625	.3383
9	.604 (52.9)	-.141 (4.0)	-.084 (.76)	.9714	.2947
10	.707 (141.)	-.219 (4.1)	-.151 (4.66)	.9830	.2276
11	.384 (14.7)	---	---	.9527	.3853
12	.477 (30.0)	-.224 (3.6)	.097 (1.19)	.9701	.2713
13	.547 (33.7)	-.115 (3.7)	-.057 (.41)	.9693	.2851
14	.759 (53.7)	-.644 (19.1)	.149 (2.65)	.9720	.2842
15	.615 (52.0)	-.201 (3.5)	-.055 (.53)	.9734	.2850
16	.558 (44.1)	-.355 (5.6)	.143 (1.95)	.9735	.2825
17	.579 (29.2)	-.090 (0.2)	-.068 (.27)	.9580	.3875
18	.616 (38.2)	-.311 (4.0)	.042 (.14)	.9673	.3163
19	.680 (86.2)	-.386 (11.5)	.019 (.06)	.9793	.2481
20	.770 (61.2)	-.458 (11.3)	---	.9696	.3270
21	.607 (59.7)	-.102 (0.8)	-.122 (2.03)	.9728	.2801
22	.366 (18.3)	-.165 (3.7)	.204 (4.44)	.9720	.3028
23	.644 (60.0)	-.265 (4.6)	-.029 (.10)	.9772	.2646
24	.662 (56.0)	-.421 (6.5)	.078 (.42)	.9702	.3185
25	.666 (60.2)	-.301 (4.3)	-.020 (.05)	.9725	.2835
26	.585 (45.0)	-.223 (3.7)	---	.9682	.3063
27	.468 (27.6)	-.026 (0.2)	-.030 (.11)	.9650	.3233
28	.670 (43.7)	-.310 (5.5)	---	.9692	.3060
29	.597 (27.6)	-.278 (2.5)	.033 (.05)	.9545	.3743
30	.725 (78.7)	-.320 (6.4)	-.067 (.58)	.9757	.2698
31	.533 (26.7)	-.453 (6.3)	.250 (3.89)	.9587	.3566
32	.692 (77.0)	-.333 (6.1)	-.026 (.09)	.9786	.2526
33	.629 (40.5)	-.269 (3.5)	-.013 (.01)	.9814	.2435

a sufficient explanatory power to contribute a significant amount to the model. In all cases the F statistic associated with this variable was very low as is shown in Table 4-3. The parameter γ is therefore not significantly different from zero. This is not surprising for a number of reasons. First, it was discussed in the previous chapter that the majority of travellers used the nearest airport and that access time variations between the different trip data records were not large. Second, compared with the effect of schedule frequency, the access time effect seems dwarfed. This is also not hard to explain. Consider two departure frequency levels, 100 flights per day and 20 flights per day. Also, consider a 20 hour active travel day, thereby giving an average headway of 12 minutes and 1 hour respectively. This means the expected schedule delay, which is the hypothetical delay associated with not finding a flight at a randomly desired flight time, may vary from 6 minutes in one case to 30 in the other. This argument is based on the principle that if flight times and desired departure time are random then the expected wait for a flight equals one half the average headway. A variation from 6 to 30 minutes means a 5-fold change in schedule delay. It is clear that while a traveller may be faced with a choice of two routes offering frequencies of the order of 100 and 20 daily flights, thus causing a 5-fold difference in the traveller's expected schedule delay, it is hardly likely that within the study area a traveller will ever be faced with the choice among two routes with a 5-fold difference in access travel time. While this argument may improve the credibility of the results obtained in this analysis, it should still be kept in mind that these results are

based on one single data file; and one that is not free of imperfections.

The next step was to examine the overall statistical goodness of fit of the least squares estimation of the parameters. This was done by computing the R^2 values and the standard error of estimate values for all 33 regressions. The R^2 values varied from 0.9830 to 0.9527 and the standard error of the estimate varied from 0.2276 to 0.3853. These results indicate an unquestionably good fit. It was therefore, concluded that the estimates of the parameters were acceptable.

The results of the regressions on the non-business travel file were quite similar to those of the business travel results. 30 estimates of α , 28 of β , and 30 of γ were obtained. These are shown in Table 4-4. Validity of parameter signs and overall statistical fit were also very similar to the estimates for business travel. R^2 values varied in the range 0.9747 to 0.9098, and standard error of estimate values from 0.2739 to 0.5835. This again represents a reliable estimation of the parameters.

The next step was then to estimate the density distribution of each of the estimates based on the values obtained in the regressions. This was done for all three parameters α , β , and γ , in spite of the fact that γ was previously judged not significant. The reason for this was to allow the investigation of any effect, regardless of its significance of access time on the choice process. Furthermore, it was decided that by including all parameters in the analysis, a process would be developed that is sufficiently general to allow its use in other empirical situations. This will only allow the corroboration of the rather limited results of this study.

TABLE 4-4 ELASTICITY ESTIMATES OF ROUTE CHARACTERISTICS FOR
NON-BUSINESS TRAVEL (F-STATISTICS SHOWN IN PARENTHESIS)

SAMPLE NUMBER	DEPARTURE FREQUENCY ELASTICITY	TRAVEL COST ELASTICITY	ACCESS TIME ELASTICITY	R ²	STANDARD ERROR
1	.320 (5.6)	-.652 (3.1)	.494 (3.34)	.9447	.4050
2	.310 (4.2)	-.345 (1.3)	.343 (.76)	.9098	.5835
3	.494 (28.9)	---	-.100 (.25)	.9630	.3395
4	.159 (6.0)	-.556 (3.7)	.584 (6.32)	.9525	.3923
5	.335 (6.4)	-.169 (2.3)	.185 (.74)	.9392	.4327
6	.301 (6.4)	-.550 (3.4)	.435 (3.94)	.9516	.3532
7	.264 (7.2)	-.912 (5.3)	.707 (6.95)	.9613	.3502
8	.313 (9.9)	-.823 (4.1)	.632 (5.57)	.9585	.3813
9	.428 (8.1)	-.468 (3.9)	.296 (1.26)	.9508	.3971
10	.498 (21.9)	-.454 (3.3)	.223 (1.33)	.9586	.3555
11	.619 (30.3)	-.590 (4.3)	.207 (1.29)	.9582	.3502
12	.533 (40.4)	-.409 (4.7)	.169 (1.02)	.9747	.2739
13	.152 (4.1)	-.282 (2.4)	.428 (2.07)	.9495	.4247
14	.314 (7.6)	-.309 (3.9)	.300 (1.86)	.9545	.3894
15	.069 (3.3)	-.563 (4.6)	.646 (5.00)	.9303	.4604
16	.304 (5.1)	-.830 (5.5)	.630 (6.92)	.9409	.4462
17	.220 (5.6)	-.582 (4.7)	.552 (3.33)	.9372	.4593
18	.539 (13.8)	-.390 (3.8)	.163 (.37)	.9401	.4258
19	.152 (4.3)	-.564 (5.0)	.600 (5.13)	.9443	.4284
20	.346 (17.3)	-.309 (3.4)	.255 (2.02)	.9659	.3159
21	.593 (22.3)	-.379 (4.4)	.104 (.19)	.9562	.3775
22	.299 (13.0)	-.369 (3.6)	.346 (5.61)	.9718	.3022
23	.492 (22.7)	-.516 (4.0)	.263 (1.67)	.9664	.3100
24	.327 (6.2)	-.695 (3.4)	.523 (4.04)	.9412	.4297
25	.285 (5.0)	-.774 (4.8)	.613 (5.66)	.9556	.3739
26	.292 (5.3)	---	-.033 (.01)	.9467	.4351
27	.719 (23.0)	-.490 (4.6)	.093 (.15)	.9570	.3865
28	.327 (6.4)	-.060 (1.0)	.140 (.35)	.9482	.4161
29	.231 (5.5)	-.225 (3.4)	.314 (1.75)	.9394	.4438
30	.135 (4.7)	-.726 (4.3)	.721 (9.77)	.9548	.3990

The estimation of the density distribution functions of the parameters α , β , and γ was performed by first inspecting the graphical representations of the distribution functions, and then testing the fit to postulated statistical distribution functions. There is no obvious relationship between behavioral assumptions and specific statistical distribution functions. At this stage of limited knowledge regarding the behavioral implications of stochastic aggregation in travel demand models, the best that can be done is empirical analysis.

In order to obtain graphical representations of the empirical distributions of the parameters α , β , and γ it was necessary to define intervals within the range of each and to observe the frequencies in each interval. Cumulative histograms were thus obtained for each parameter.

These histograms are shown for the business and the non-business travel cases separately on Figs. 4-3 through 4-8. They are shown together with the hypothesized theoretical distributions and the 95% confidence band for each. Gamma distributions were postulated for the parameters α and β , while a normal distribution was postulated for γ , in both the business and the non-business cases. After the estimation of the parameters of these hypothesized distributions from the respective data sets, statistical tests of goodness of fit were performed. χ^2 tests were performed on all six distributions. These tests showed in all cases that the empirical distributions and the hypothesized theoretical distributions were not significantly different. This inference was drawn from the high p-values obtained for these tests. In addition to the χ^2 tests, D-tests were conducted to check

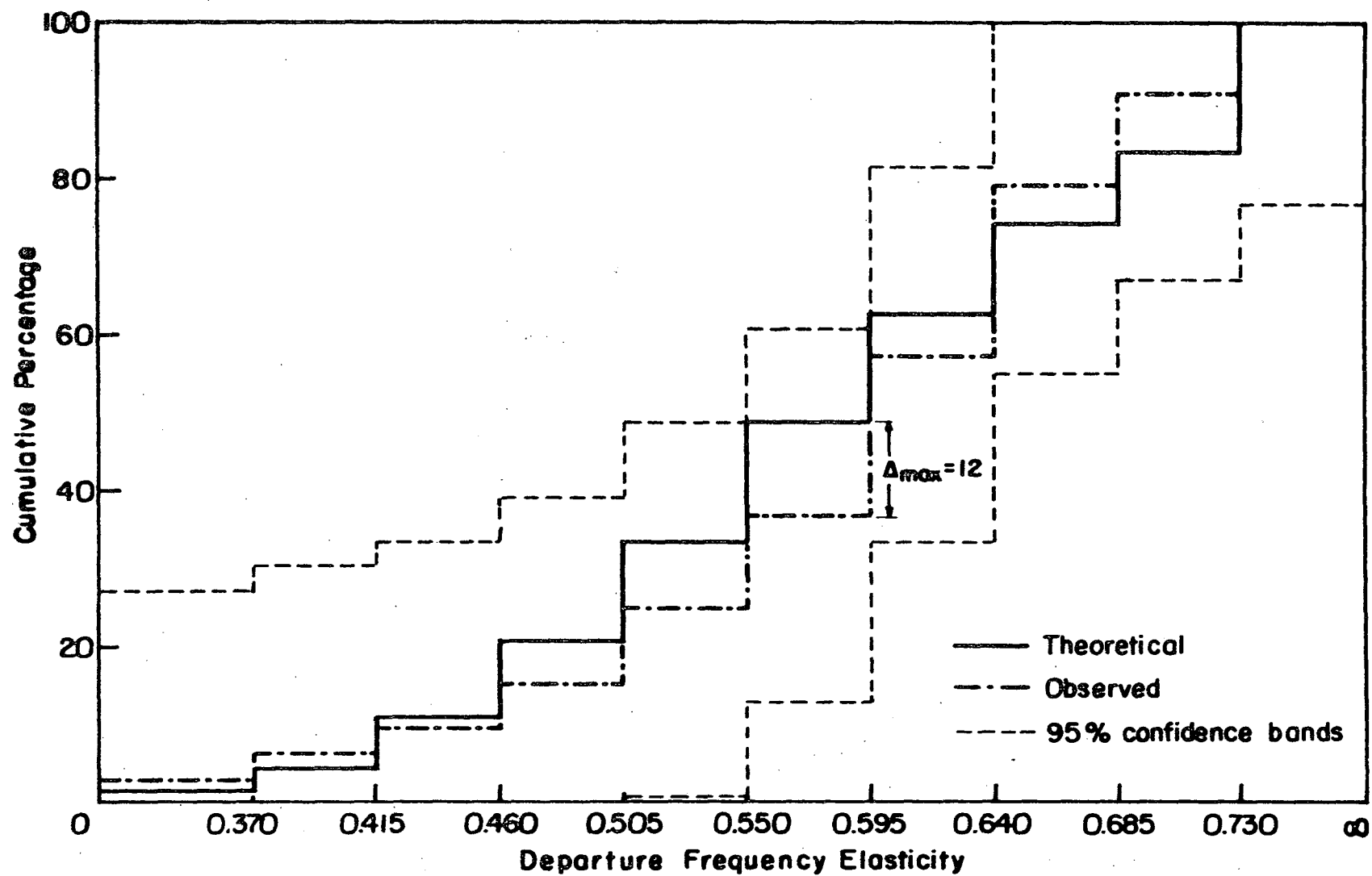


Figure 4-3 Cumulative Distribution of Departure Frequency Elasticity for Business Travelers

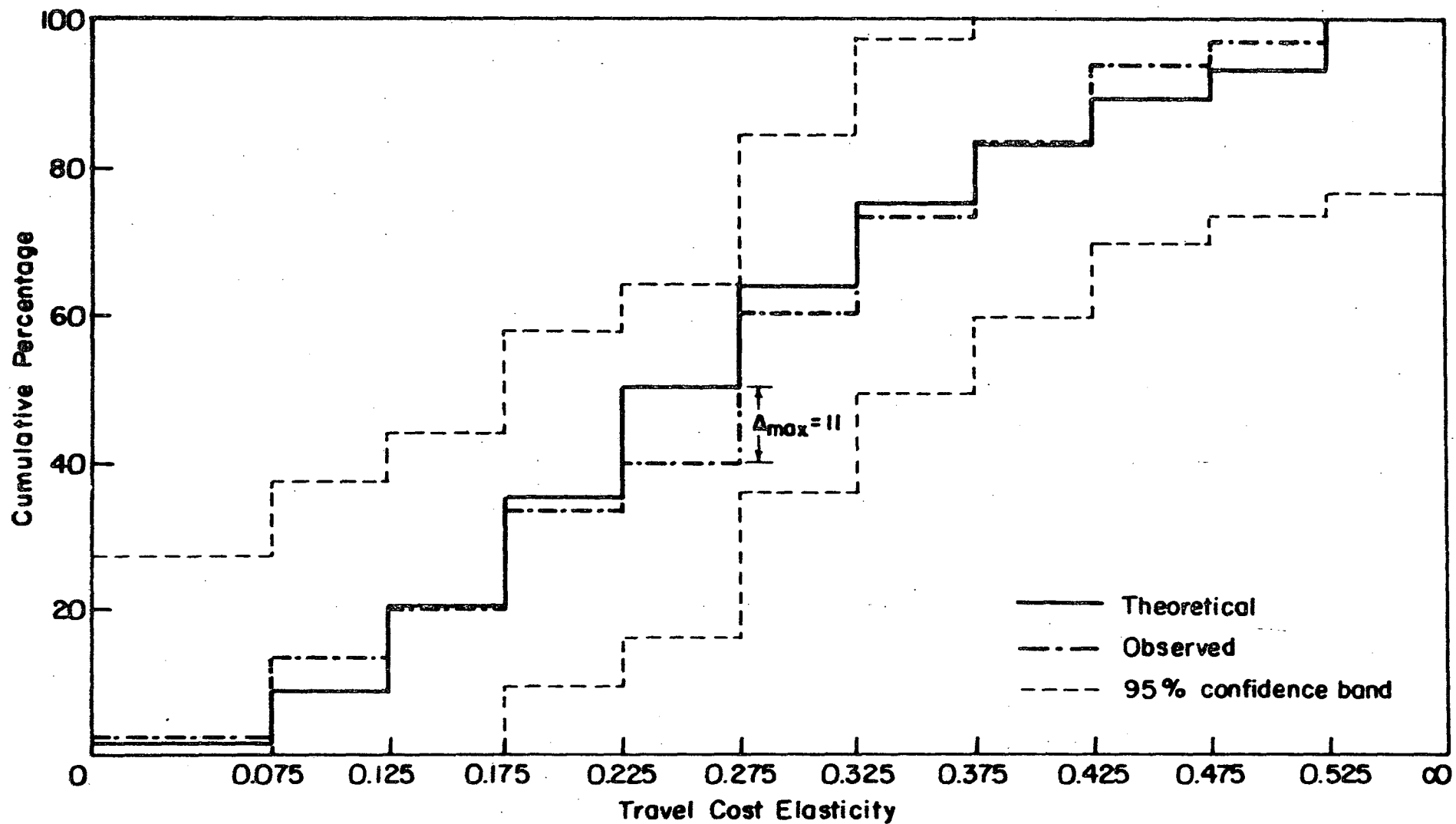


Figure 4-4 Cumulative Distribution of Travel Cost Elasticity for Business Travelers

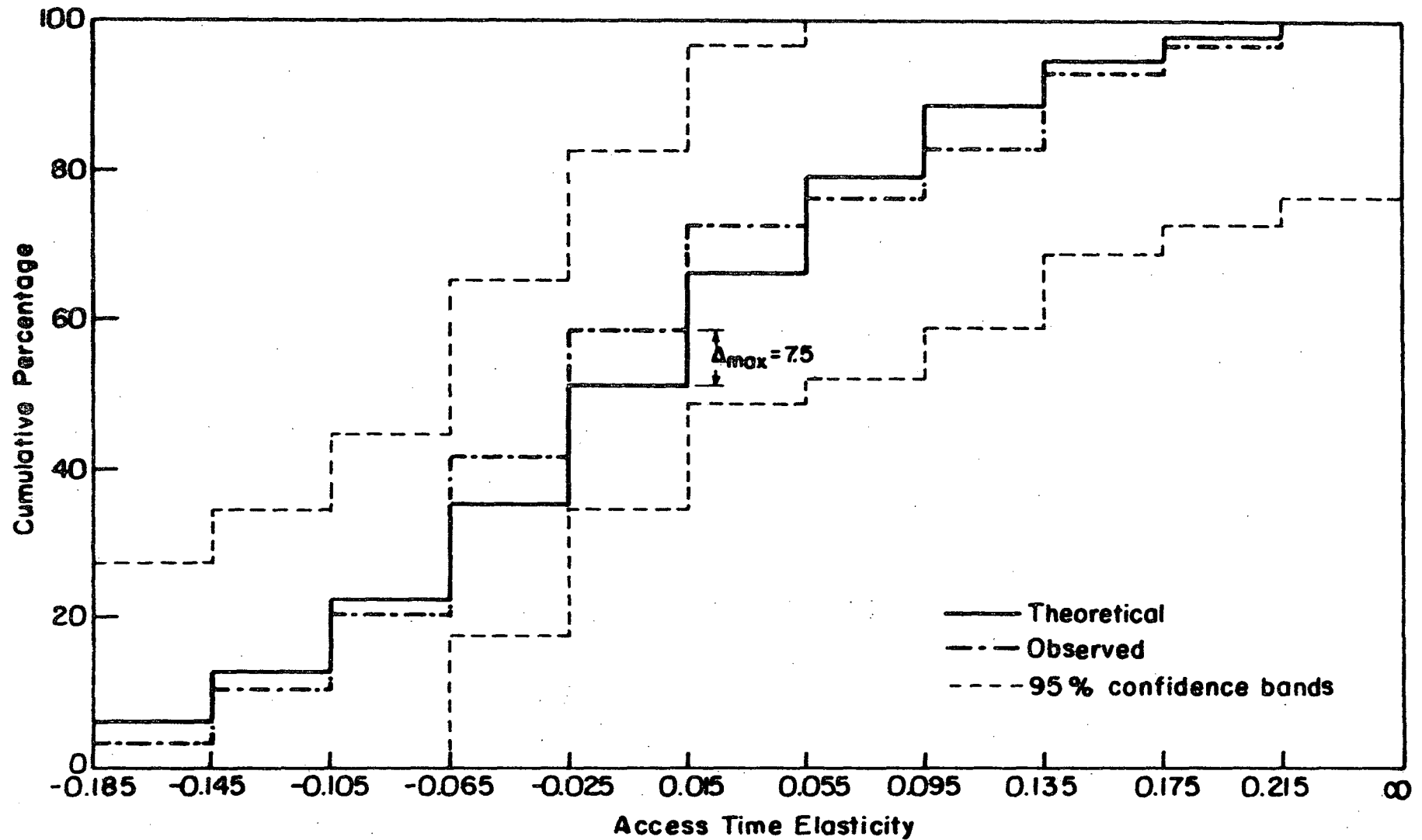


Figure 4-5 Cumulative Distribution of Access Time Elasticity for Business Travelers

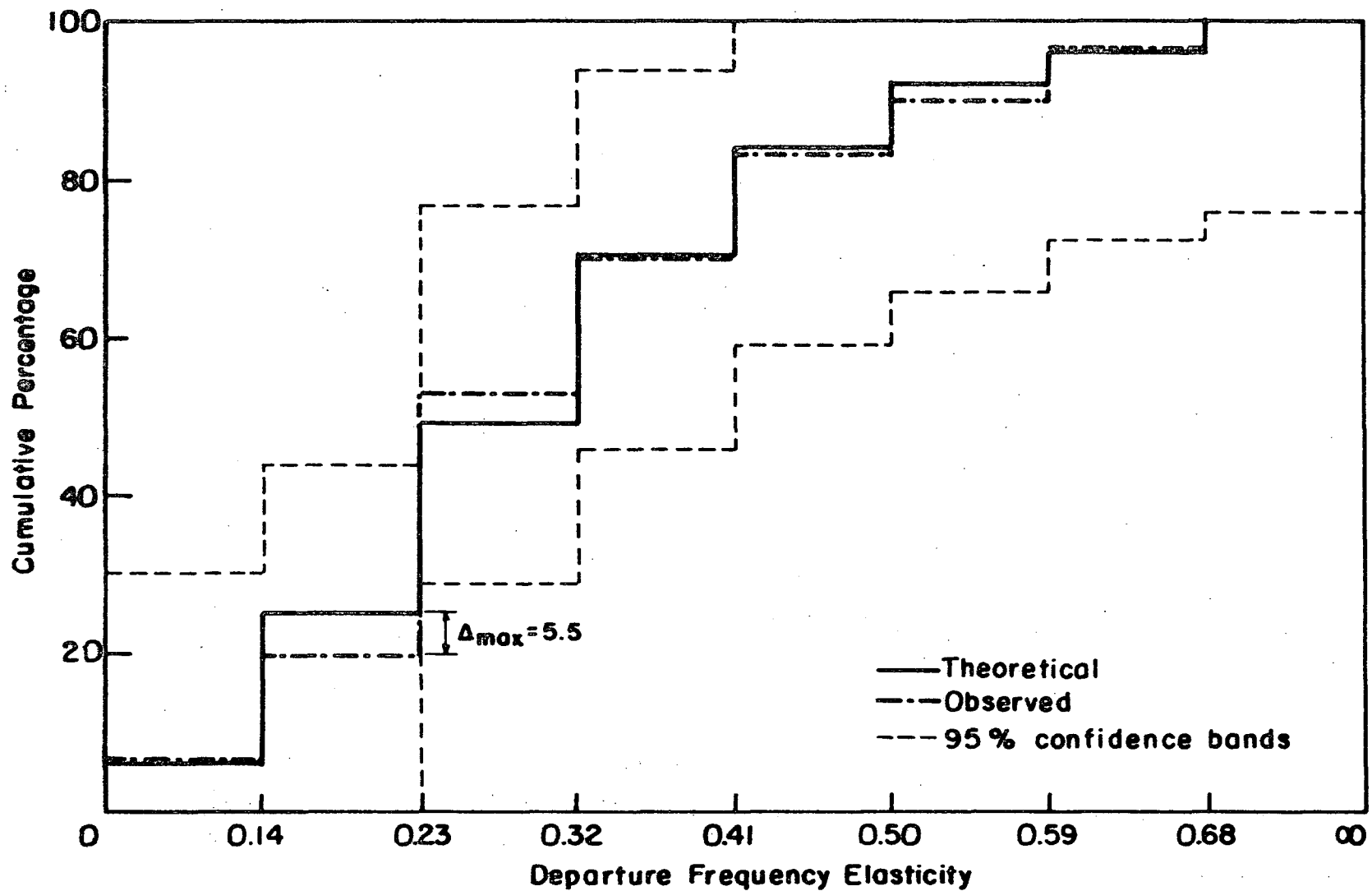


Figure 4-6 Cumulative Distribution of Departure Frequency Elasticity for Non-Business Travelers

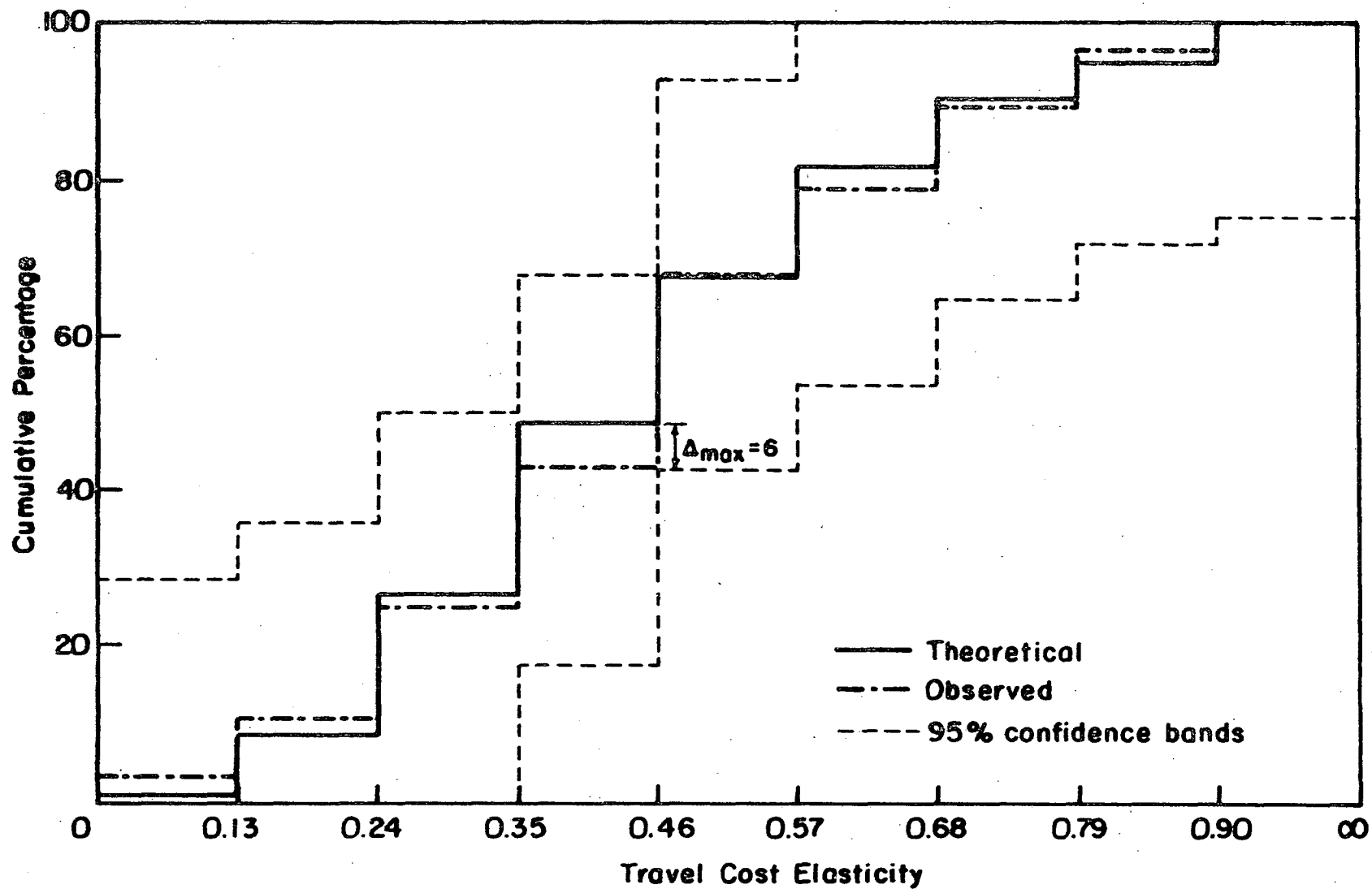


Figure 4-7 Cumulative Distribution of Travel Cost Elasticity for Non-Business Travelers

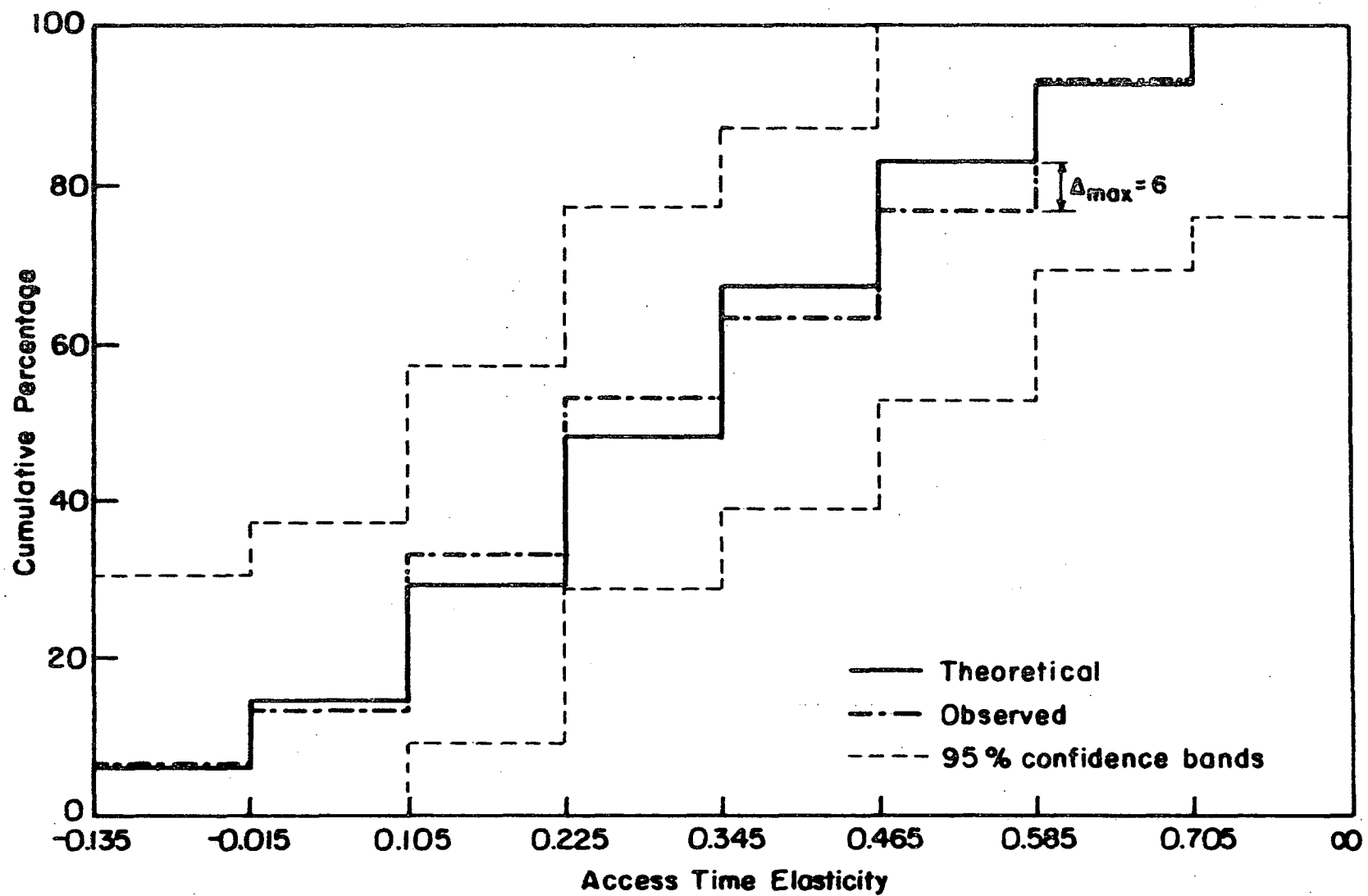


Figure 4-8 Cumulative Distribution of Access Time Elasticity for Non-Business Travelers

the goodness of fit of the parameter distributions. The purpose was to corroborate the results of the X^2 tests and to remove any doubt that may be precipitated because of the X^2 -test's sensitivity to small sample sizes. The D-test results are shown on the frequency diagrams of Figs. 4-3 through 4-8. in the form of the 95% confidence bands. As can be seen from these figures all theoretical distributions fall within these bands, it can be concluded that the theoretical distributions postulated for the parameters α , β , and γ are valid representations of these random variables. The equations for the theoretical distributions as well as the results of the X^2 tests are summarized in Table 4-5.

With the density functions $f_1(\alpha)$, $f_2(\beta)$, and $f_3(\gamma)$ now estimated, the final step in the calibration of the choice model is the evaluation of the three-dimensional integral of Eq. (4.8). As mentioned earlier, it was found not possible to evaluate the integration analytically. If an integral is finite, then it is always possible to evaluate it numerically with the aid of a high speed computer. It is easy to tell from inspection of the integrand

$$\frac{F_{ijk}^{\alpha} C_{ijk}^{\beta} H_{ijk}^{\gamma}}{\sum_k F_{ijk}^{\alpha} C_{ijk}^{\beta} H_{ijk}^{\gamma}} f_1(\alpha) f_2(\beta) f_3(\gamma)$$

that it is indeed finite. The first part of the integrand is a ratio known to be less than unity and the second part is the joint density functions of three random variables and is also limited to unity.

Numerous techniques are available for evaluating such an integral. Some are more accurate than others, but often the more accurate the

TABLE 4.5 ~ SUMMARY OF ELASTICITY DENSITY DISTRIBUTIONS CALIBRATED
AND RESULTS OF χ^2 - TESTS

$$\text{Gamma Distribution} - f(x) = \frac{\lambda^K}{\Gamma(K)} x^{K-1} e^{-\lambda x}$$

$$\text{Normal Distribution} - f(x) = \frac{1}{\sqrt{2\pi} \sigma} e^{- (x - \mu)^2 / 2\sigma^2}$$

Trip Purpose	Variable	Gamma Distribution			Normal Distribution		Degrees of Freedom	χ^2 Calculated	P-Value
		K	λ	$\Gamma(K)$	μ	σ			
Business	α	23.72	38.96	1.05×10^{22}	-	-	5	6.042	.3019
	β	4.28	14.43	8.63	-	-	4	3.925	.4170
	γ	-	-	-	.0136	.1068	3	3.244	.3592
Non-Business	α	4.64	13.43	14.13	-	-	2	1.596	.4531
	β	5.33	10.69	40.19	-	-	2	1.033	.5964
	γ	-	-	-	.363	.247	3	2.650	.4520

technique is the more costly its application in terms of computer time. For an integral of three dimensions only it was decided to use the technique called "Multiple Integrations Using Simpson's One-Third Rule".* It is a technique which is reasonably accurate yet sufficiently efficient in terms of computer time. However, its efficiency is limited to small dimension intergals such as the one in question here. For a larger dimension intergal a Monte Carlo simulation would probably have been necessary.

To perform the numerical analysis, a computer program called SHARE was prepared. The route characteristics of the 12 alternative routes of the study corridor were imputed and the model was operated in an attempt to reproduce the data observed. Tables 4-6 and 4-7 show the results of the application of the solution method for business and non-business travel between two zones. As shown in those tables the errors due to the numerical approximations of the integration method were about 1.7% and 2.3% for the business and the non-business cases respectively. With these results it was deemed unnecessary to expend additional computer time and refine the approximation methods any further.

The overall statistical goodness of fit of the model results were then tested. Figures 4-9 and 4-10 show the comparisons of model results with observed data for the business and the non-business travel cases, respectively.

In view of the results presented in the preceding paragraphs, and the imperfections of the data base used in calibrating the choice model,

* For a description of the numerical methods see appendix B-1.

TABLE 4-6 INTEGRATION RESULTS -- ROUTE CHOICE FOR BUSINESS TRAVEL BETWEEN TWO ZONES

AIRPORT PAIR (ROUTE)	PROBABILITY OF BEING CHOSEN FOR TRAVEL
1	.0569
2	.1374
3	.0592
4	.0723
5	.0930
6	.0418
7	.0883
8	.0850
9	.0722
10	.1227
11	.0726
12	.0813

SUM OF PROBABILITIES = .9827

NUMERICAL APPROXIMATION ERROR = 1.0 - .9827
= .0173

TABLE 4-7 INTEGRATION RESULTS -- ROUTE CHOICE FOR NON-BUSINESS TRAVEL BETWEEN TWO ZONES

AIRPORT PAIR (ROUTE)	PROBABILITY OF BEING CHOSEN FOR TRAVEL
1	.0710
2	.1118
3	.0672
4	.0622
5	.0961
6	.0528
7	.0924
8	.0710
9	.0852
10	.1130
11	.0805
12	.0735

SUM OF PROBABILITIES = .9767

NUMERICAL APPROXIMATION ERROR = 1.0 - .9767
= .0233

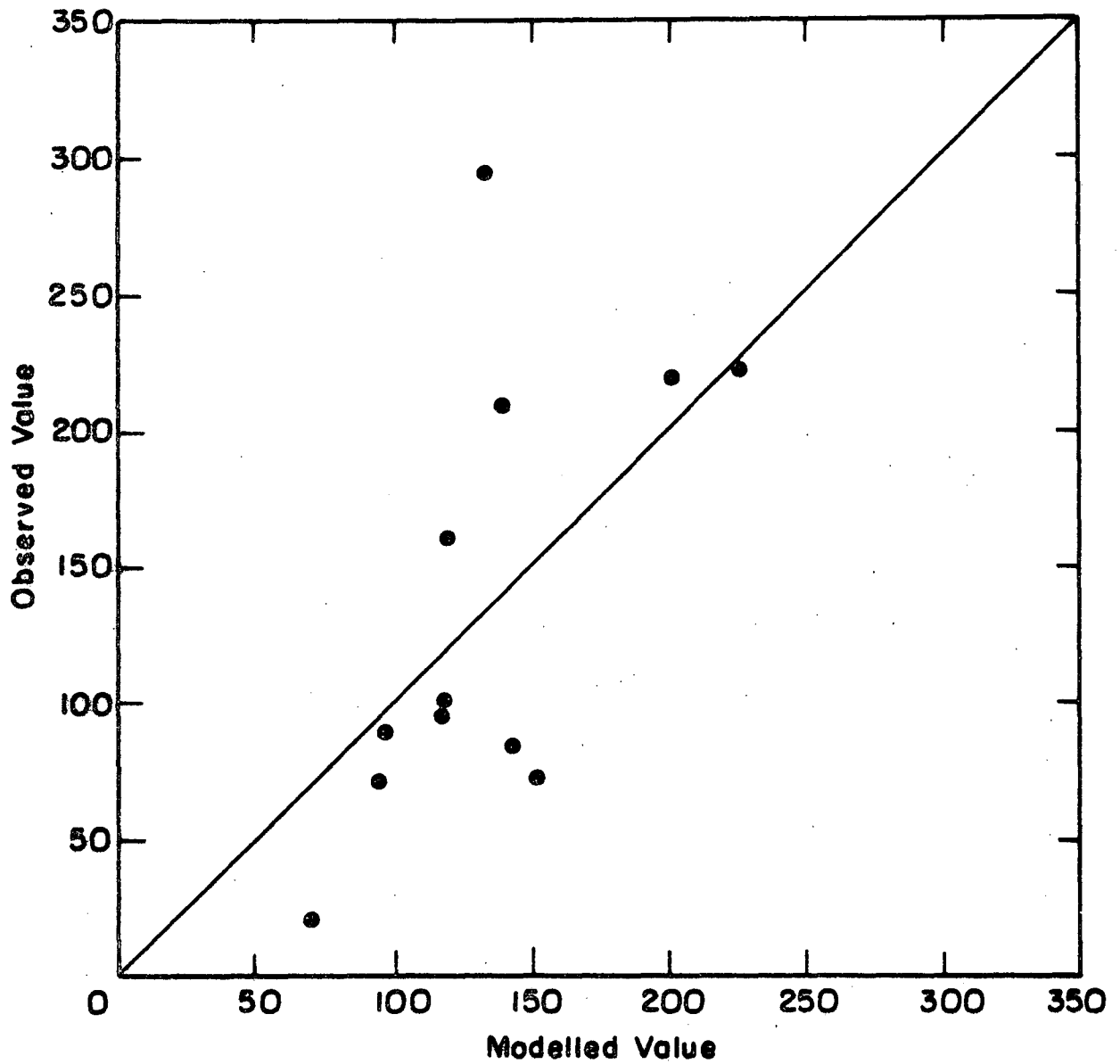


Figure 4-9 Comparison of Modelled Against Observed Business Trips on Each Route

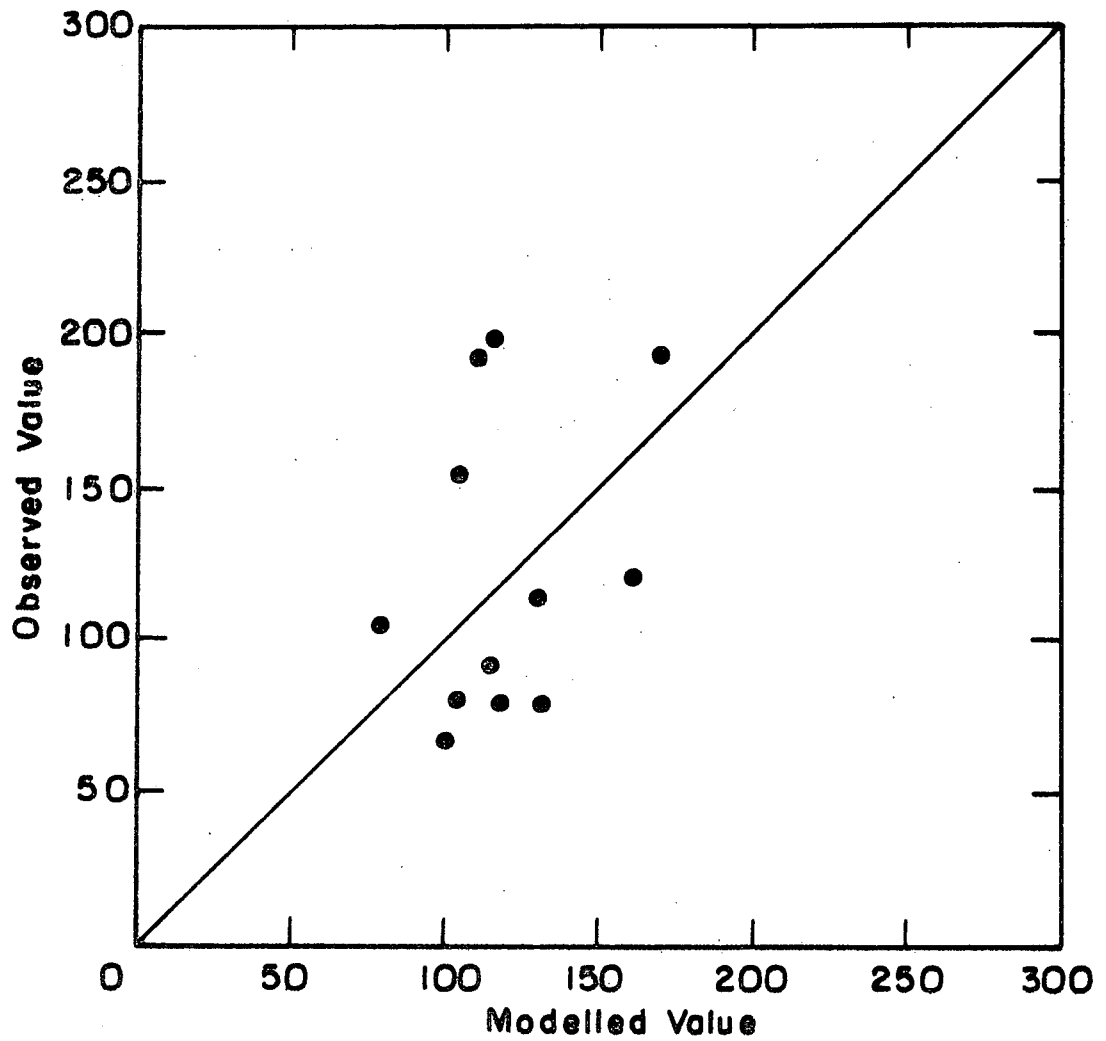


Figure 4-10 Comparison of Modelled Against Observed Non-Business Trips on Each Route

it was concluded that the statistical validity of the model results can generally be considered good. Consequently, the calibrated model is deemed to be representative of air traveller's choice behavior, and capable of providing reliable forecasts.

CHAPTER 5

DEMAND FORECASTING AND SENSITIVITY ANALYSIS

INTRODUCTION

The models designed and calibrated in the previous paragraphs were used to provide forecasts of the demand for air transport in the study corridor and of the market potential for STOL air transportation in the corridor. As described in Chapter 1 of this report, the demand forecasting process involves combining the models that describe the relationship between trip making, and socioeconomic and transportation characteristics, with the exogenous forecasts of these characteristics. Therefore, the first step in performing demand forecasting for STOL air transportation is to postulate STOL system characteristics.

A basic assumption in this approach is that the decision process by which travellers choose among available routes is essentially unchanged by the introduction of STOL transportation service. The route characteristics used in model calibration, frequency, cost, and travel time, will be specified for every postulated STOL system. This approach, called the Abstract Mode Approach, implies that to the traveller, a route is completely specified by its characteristic variables regardless of whether it is a CTOL route or a STOL route.

Another basic assumption made in the forecasting process, is that the traveller's decision process does not change over time. In other words the values of the parameters and elasticities which reflect the traveller's response to exogenous influences, will remain unchanged over the forecasting period. The validity of this assumption can only

be checked after repeated applications of the forecasting models at different points in time.

This chapter begins with a discussion of the postulated STOL service alternatives that were tested in this study. The forecasting of total corridor air travel demand is then presented. Finally, the forecasting of STOL market share and potential STOL demand are presented in the form of a sensitivity analysis.

STOL SYSTEM CONFIGURATIONS

The specification of STOL system configurations consists of specifying the locations of STOL-ports, the frequencies of service, and the travel costs and times involved. The location of STOL-ports in urban areas is an important topic by itself and basically outside the scope of this study. It is treated, as many other system variables, parametrically. That is, a number of reasonable configurations are assumed and the resulting forecasts presented. The purpose of this type of analysis is to provide a procedure by which alternative STOL system configurations can be compared, at least on the basis of their demand potential.

A number of considerations enter into the process of choosing STOL-port locations. Most important among these are the environmental considerations. In this study, the only STOL-port locations that will be considered are locations of presently existing airports. These airports are either military fields or general aviation fields. The reason for this is that such airports, by the mere fact of their presence, would probably be considered first as candidates for the

introduction of STOL air transportation into any urban area. Four such locations were considered for each end of the corridor. These are shown on the maps of Figs. 5-1 and 5-2, and are given below:

In the San Francisco Bay Area:

1. Crissy Field: presently a military field on the northern shore of the city of San Francisco.
2. Berkeley Marina: presently a VTOL-port on the western shore of the city of Berkeley.
3. Palo Alto Airport: a county general aviation field.
4. Concord Buchanan Field: A county general aviation field on the eastern side of the Bay Area.

In the Los Angeles Basin:

1. Hawthorne Airport: a municipal general aviation field equipped with control tower. It is about 3 miles from LAX.
2. Fullerton Airport: a municipal general aviation field.
3. Compton Airport: a county leased general aviation field.
4. Santa Monica Airport: a municipal general aviation field in West Los Angeles.

Needless to say, this choice of locations was made for the purpose of demonstrating the use of the forecasting models. Other system configurations could be introduced easily if required.

Different system configurations were generated by considering STOL service between different pairs of airports. This was done mainly for the purpose of demonstrating the use of the forecasting models. The process developed in this study has the flexibility to allow other

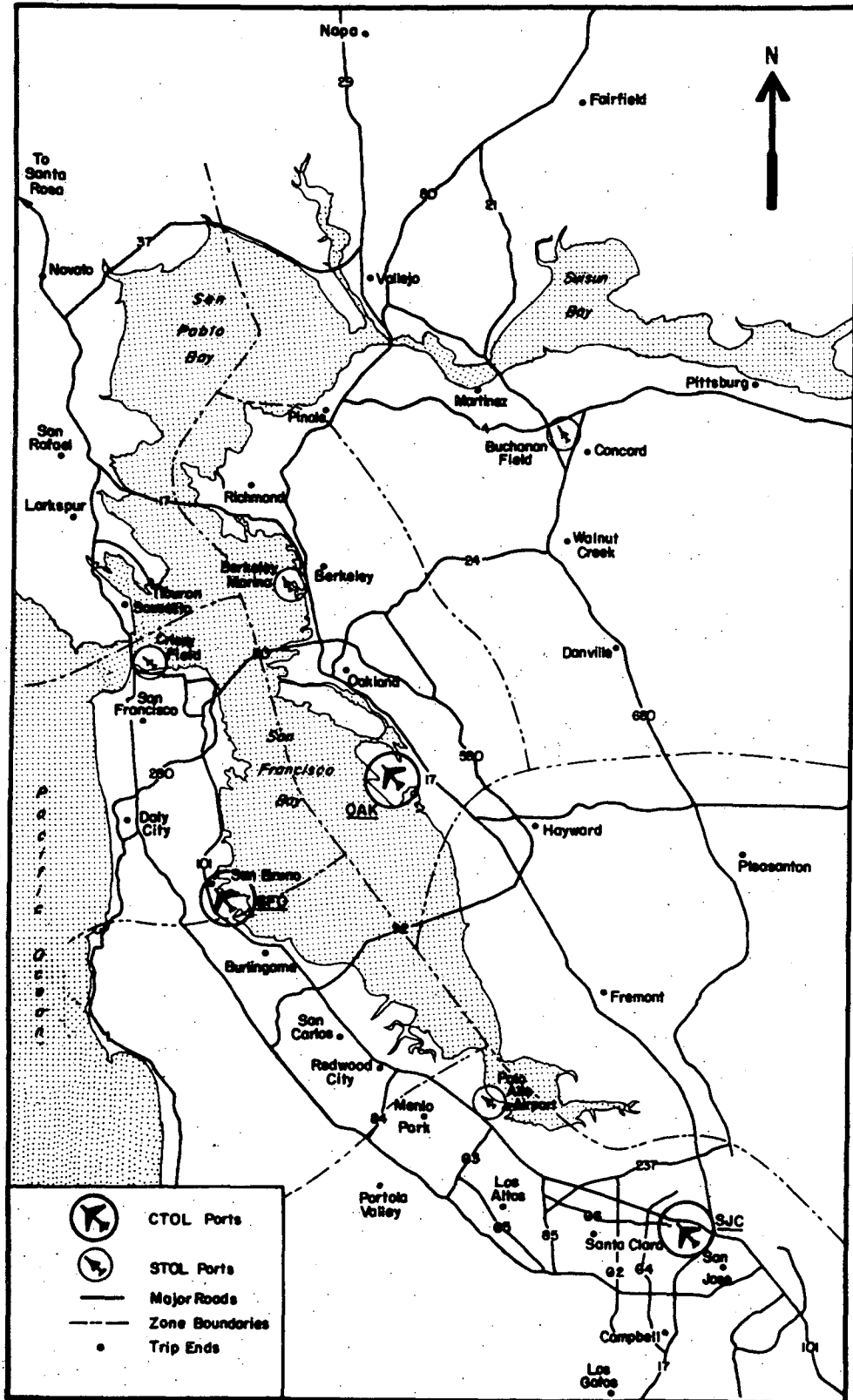


Figure 5-1 STOL-port Locations in San Francisco Bay Area

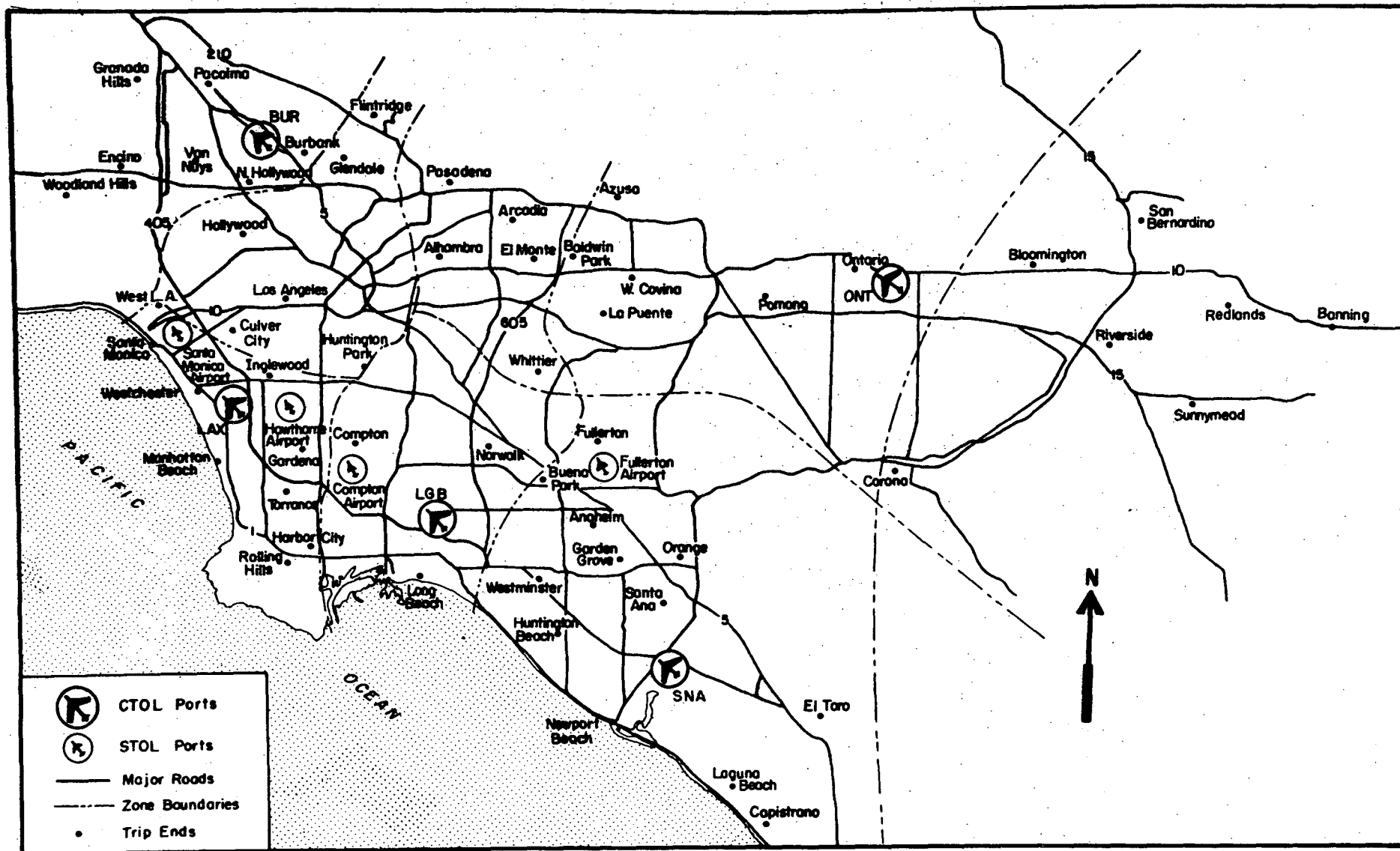


Figure 5-2 STOL-port Locations in Los Angeles Basin

locations and configurations to be considered.

In particular, this chapter presents results of the analysis that were generated by considering four distinct configurations of STOL service between the following airport pairs:

Configuration I: Crissy Field - Hawthorne

Configuration II: Crissy Field - Hawthorne
Crissy Field - Fullerton
Buchanan Field - Hawthorne
Buchanan Field - Fullerton

Configuration III: Crissy Field - Hawthorne
Crissy Field - Long Beach
Buchanan Field - Hawthorne
Buchanan Field - Long Beach

Configuration IV: Crissy Field - Hawthorne
Crissy Field - Fullerton
Crissy Field - Long Beach
Buchanan Field - Hawthorne
Buchanan Field - Fullerton
Buchanan Field - Long Beach

In the third and fourth configurations it was postulated that Long Beach airport, which is presently a CTOL airport, would be converted into a STOL-port. Again, this was done for the purpose of demonstration and was not a normative assumption in any sense.

The next step was to specify values, or ranges for the variables that describe the STOL service. Due to lack of precise data on STOL aircraft characteristics, both technical and economic, it was necessary to postulate ranges rather than values for the transportation variables. These ranges were selected after a review of published information on

potential configurations of STOL aircraft.

Fares were calculated according to the following formula:

$$\text{Fare} = \frac{\text{Total cost per available seat-mile} \times \text{stage length}}{\text{Load factor}} + \text{tax}$$

The range of total cost per available seat-mile was set to vary from 2¢ to 4¢ for a stage length of 400 miles. The load factor range was 0.5 - 0.7. The frequency of service was allowed to vary in two manners. First STOL service frequency was increased from 0 to 49 weekly flights, without adjusting the frequency of service of the CTOL airport pairs. Then it was postulated that some CTOL service will essentially be replaced by STOL service, and the increase in STOL frequency was accompanied by an equal decrease in CTOL frequency. Finally, access times to the STOL-ports were obtained in the same manner as the rest of the access time information, i.e. from the road maps of the California Automobile Association, as described in Chapter 3.

With all these specifications the calibrated models were then applied and demand forecasting was done in the form of a sensitivity analysis as is described in the following sections.

FORECASTING TOTAL AIR TRAVEL

Forecasting total air travel demand in the study corridor was done using two separate models, one for business travel and another for non-business travel. As was discussed in Chapter 3, the calibration results showed that the models were not sufficient to forecast the absolute levels of traffic between city pairs. However, the elasticities of demand with respect to the population, income, and travel time variables were estimated with high reliabilities. Therefore, these elasticities were used to relate the increase in travel volumes to

varying growth rates in population and income, and to the changes in travel times caused by the introduction of STOL-ports in the study area.

The models selected were the following:

For business travel:

$$\ln(T_{ij}) = (-7.32) + 0.29 \ln(P_i) + 0.37 \ln(P_j) + 0.89 \ln(Y_{ij}) - 0.33 \ln(t_{ij})$$

and for non-business travel:

$$\ln(T_{ij}) = -15.65 + 0.31 \ln(P_i) + 0.42 \ln(P_j) + 1.40 \ln(Y_{ij})$$

where, as before:

T_{ij} annual trips between city analysis zones i and j

P total zonal population

Y_{ij} the average of the median incomes in zones i and j

t_{ij} the shortest travel time between the zones i and j.

In order to obtain the percent increase in T_{ij} that is brought about by corresponding increases in the explanatory variables, Eqs. (3.7) in Chapter 3 is used. The equation is re-written as follows:

$$\frac{\Delta T_{ij}}{T_{ij}} = \alpha_1 W_{p_i} + \alpha_2 W_{p_j} + \alpha_3 W_{Y_{ij}} + \alpha_4 W_t \quad (5.1)$$

where α_k represents the elasticities with respect to variable k

W_k represents a proportional change in variable k

We assume that population and income growth occur in the same manner in all zones and simplify Eq. (5.1) to

$$\Delta T_{ij}/T_{ij} = (\alpha_1 + \alpha_2) W_p + \alpha_3 W_Y + \alpha_4 W_t \quad (5.2)$$

we denote $\Delta T_{ij}/T_{ij}$ by β , and the number of years over which the forecast is performed by N . Future traffic volumes T_{ij}^* can be obtained from present volumes T_{ij} by:

$$T_{ij}^* = (1 + \beta)^N \quad (5.3)$$

The total corridor travel T^* at year N can be obtained by summing over all zone pairs:

$$\begin{aligned} T^* &= \sum_{ij} T_{ij} (1 + \beta)^N \\ &= T(1 + \beta)^N \end{aligned} \quad (5.4)$$

This procedure relates future travel volumes in each city pair to present volumes thus avoiding zone-by-zone errors that may be introduced if the absolute volume levels were to be forecast directly from a model. The procedure was applied to forecast corridor volume under various hypothesized rates of growth of population and income.

Population growth rates were varied within the range 0.5 - 2.0 percent annual increase. Median income was increased in the range 5.0 - 7.0 percent per year. The forecast was performed for values of N of 10, 15, and 20 years. For the STOL system configuration, the following assumptions were made. During the first 10 years, i.e. up to the year 1980, no service will be introduced at any of the STOL-ports. In 1980 service will be introduced at the airport pair: Crissy Field - Hawthorne. Travel times will therefore be modified, but then held unchanged throughout the rest of the forecasting period.

The results of model application are shown in Figs. 5-3 through 5.4.

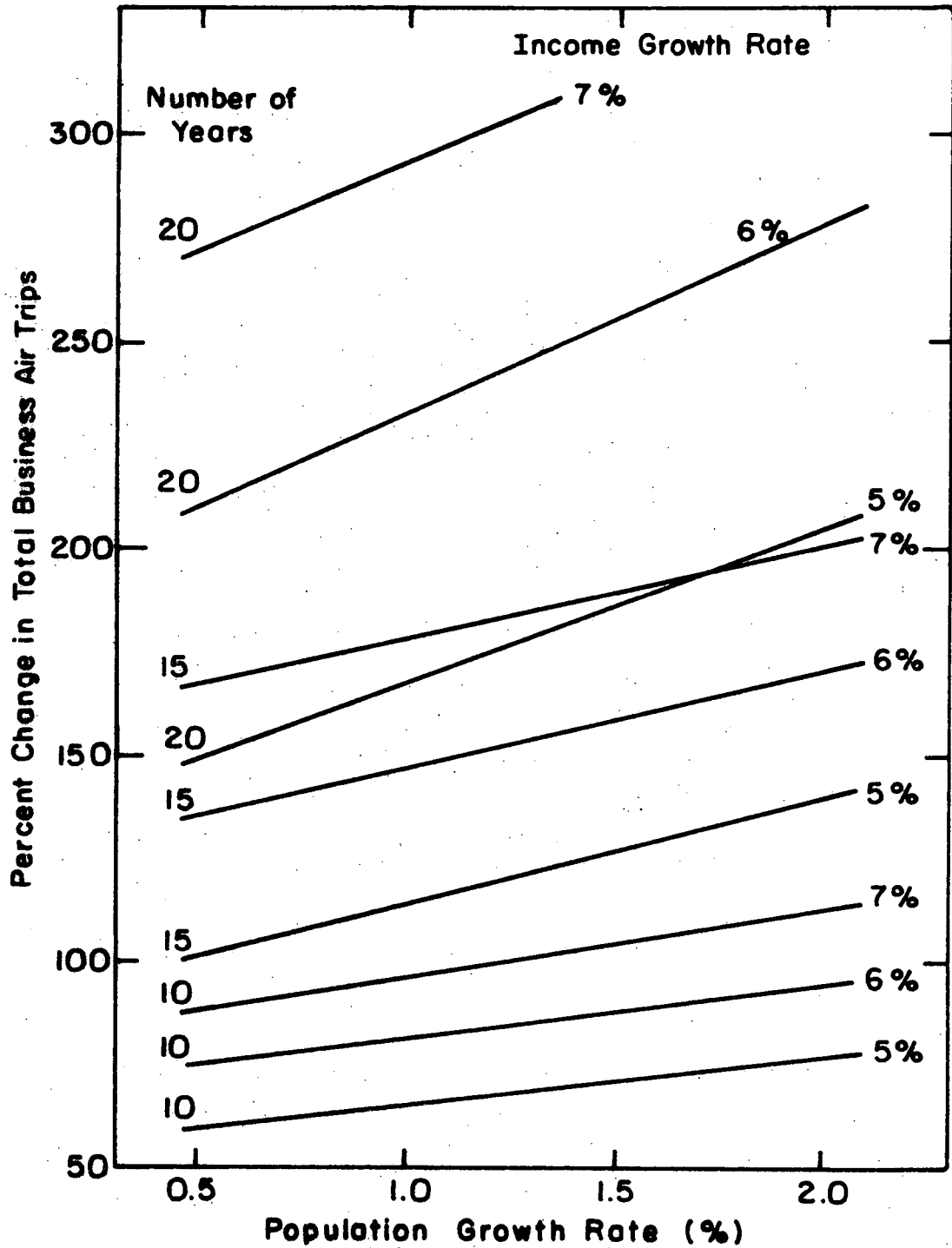


Figure 5-3 Sensitivity of Business Travel to Population and Median Family Income Changes

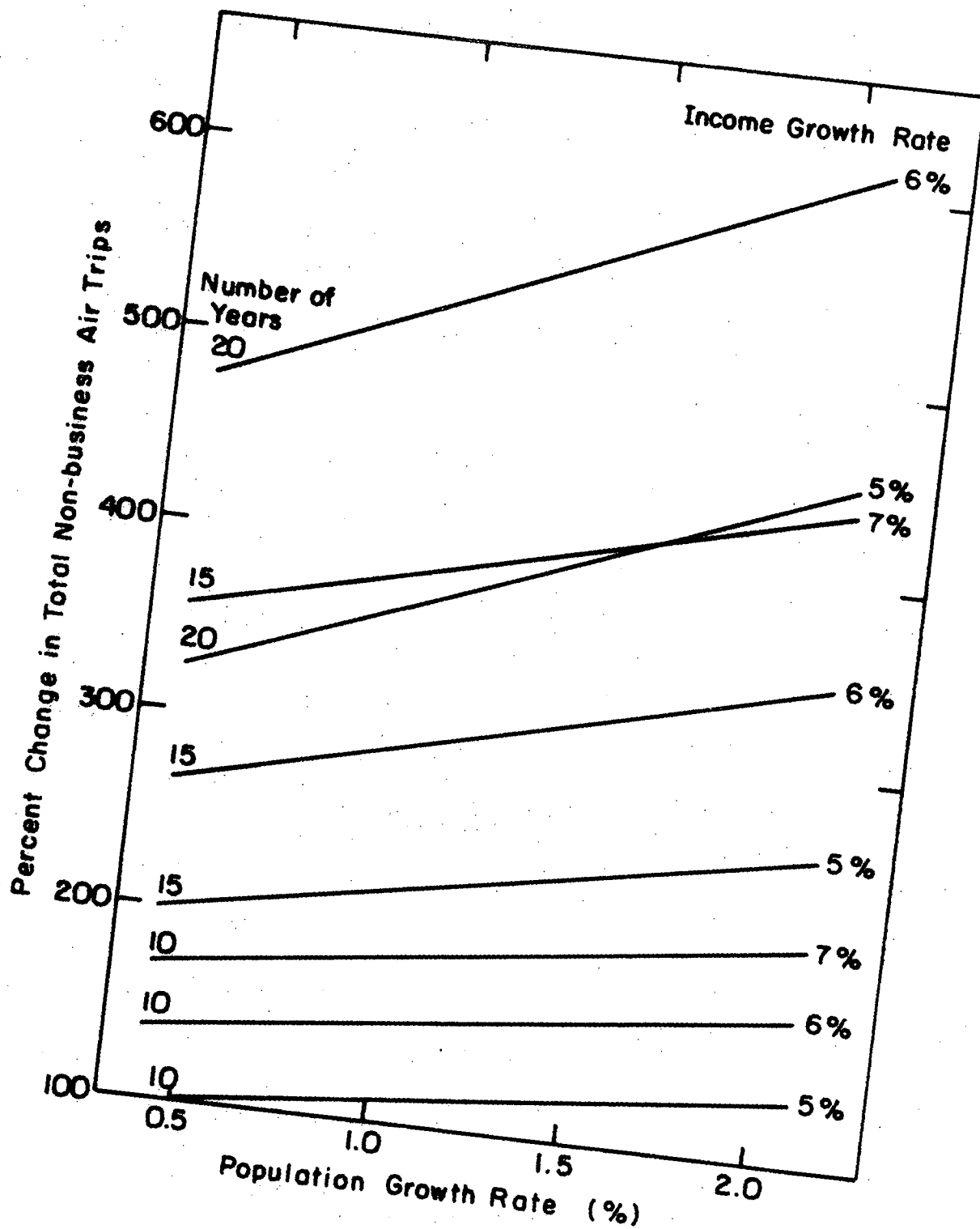


Figure 5-4 Sensitivity of Non-Business Travel to Population and Median Family Income Changes

It should be mentioned again that these results are samples of the types of results that can be obtained from the application of the travel generation model. This application allows the estimation of the increase in total corridor air travel population and income growth assumptions and for different air transport system alternatives.

FORECASTING STOL MARKET SHARE

The STOL market share potential was forecast using the model of Eq. (2.20) in Chapter 2, together with the calibrated parameters discussed in Chapter 4. The four STOL system configurations described earlier in this Chapter were postulated and the transportation variables frequency and travel cost were allowed to vary within the specified ranges. The model was then applied to estimate the potential share of the market that is captured by STOL. Some of the results of this application are presented in this section. The appendix to this Chapter contains the remainder of these results.

The first model application consisted of varying STOL load factors and departure frequency without adjustment to CTOL frequency. The STOL system configuration used was Configuration I, (one STOL-port pair: Crissy Field - Hawthorne). Figures 5-5 and 5-6 show the results for business and non-business travel respectively. The results shown are for a fare derived from 2¢ per available seat mile. The results for other fares are shown in the Appendix. The results show the increasing STOL market share brought about by the increasing service frequencies. They also show how the market share increases with load factor. With a constant rate per available seat mile the fare per

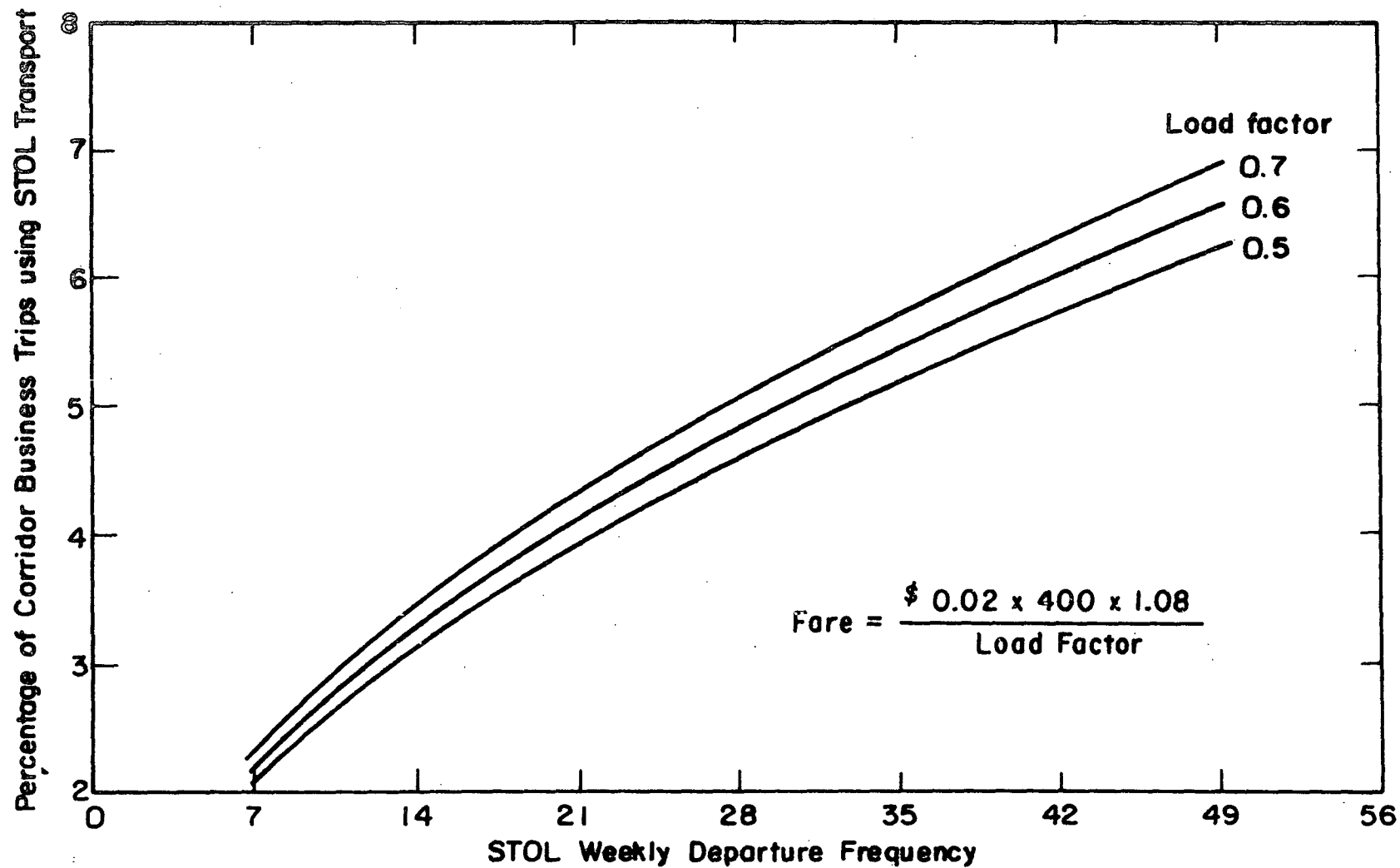


Figure 5-5 Sensitivity of STOL Share of the Business Travel Market to Departure Frequency (Configuration I)

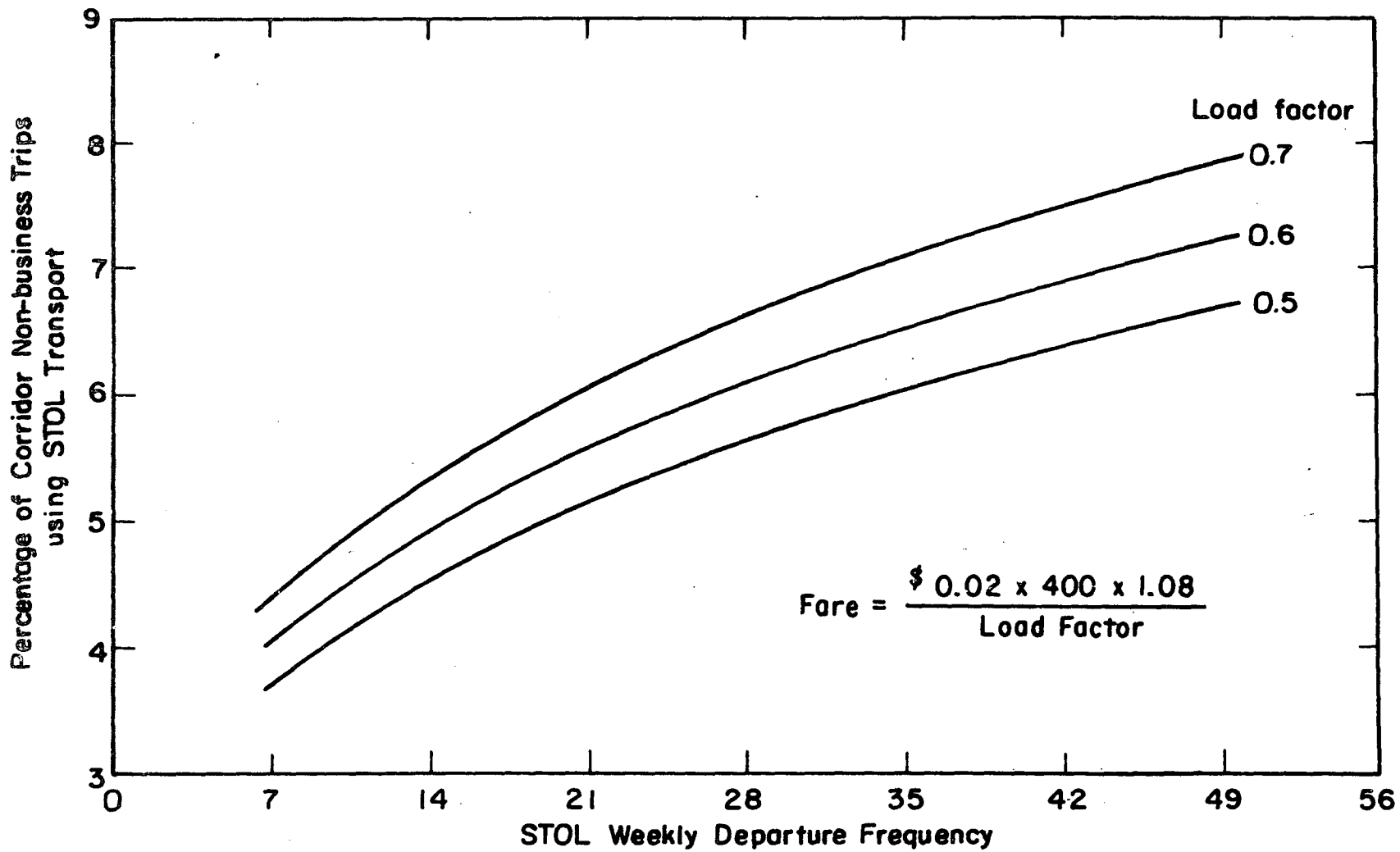


Figure 5-6 Sensitivity of STOL Share of the Non-Business Travel Market to Departure Frequency (Configuration I)

passenger decreases with increasing load factor; causing the market potential to rise. By comparing the results in Fig. 5-5 and 5-6 it can be seen that business travel is more sensitive to departure frequency than non-business travel; the curves for business travel being steeper than those for non-business travel. It can also be seen by comparing the distances between the curves for different load factors that non-business travel is more sensitive to fare than business travel.

Figures 5-7 and 5-8 show the results when the load factor is held constant at 0.5 but the basic fares are changed. For Configuration I and for varying schedule frequency level, these results also show that non-business travel is more sensitive to fare than business travel.

In both cases, with configuration I it is seen that the market share for STOL does not exceed 7 percent of the total.

Configuration II was then postulated. This configuration consists of two airports on either side of the study corridor, thus providing four STOL-port pairs. Similar analyses were performed for this configuration as for configuration I. The results, are shown in Figs. 5-9 through 5-12.

The same trends are observed in the case of configuration II as was observed previously for configuration I. The difference, however, is that in the case of Configuration II market share rose considerably. The maximum share now ranging between 20 and 25 percent of the total. This indicates the strong relationship between total STOL market share and the number of STOL-ports available in the corridor.

The next step in the analysis was to introduce adjustments in the

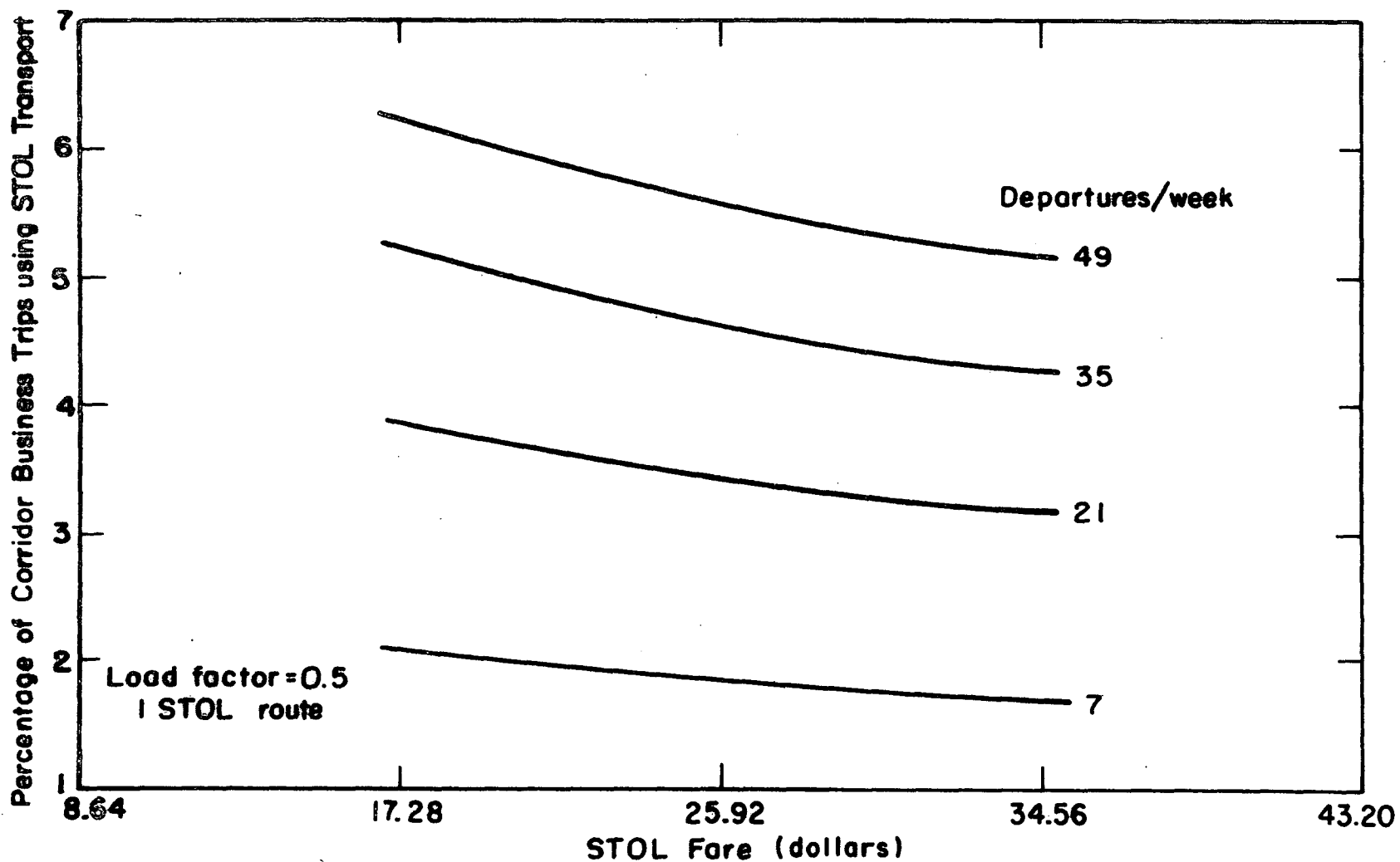


Figure 5-7 Sensitivity of STOL Share of the Business Travel Market to STOL Fare (Configuration I)

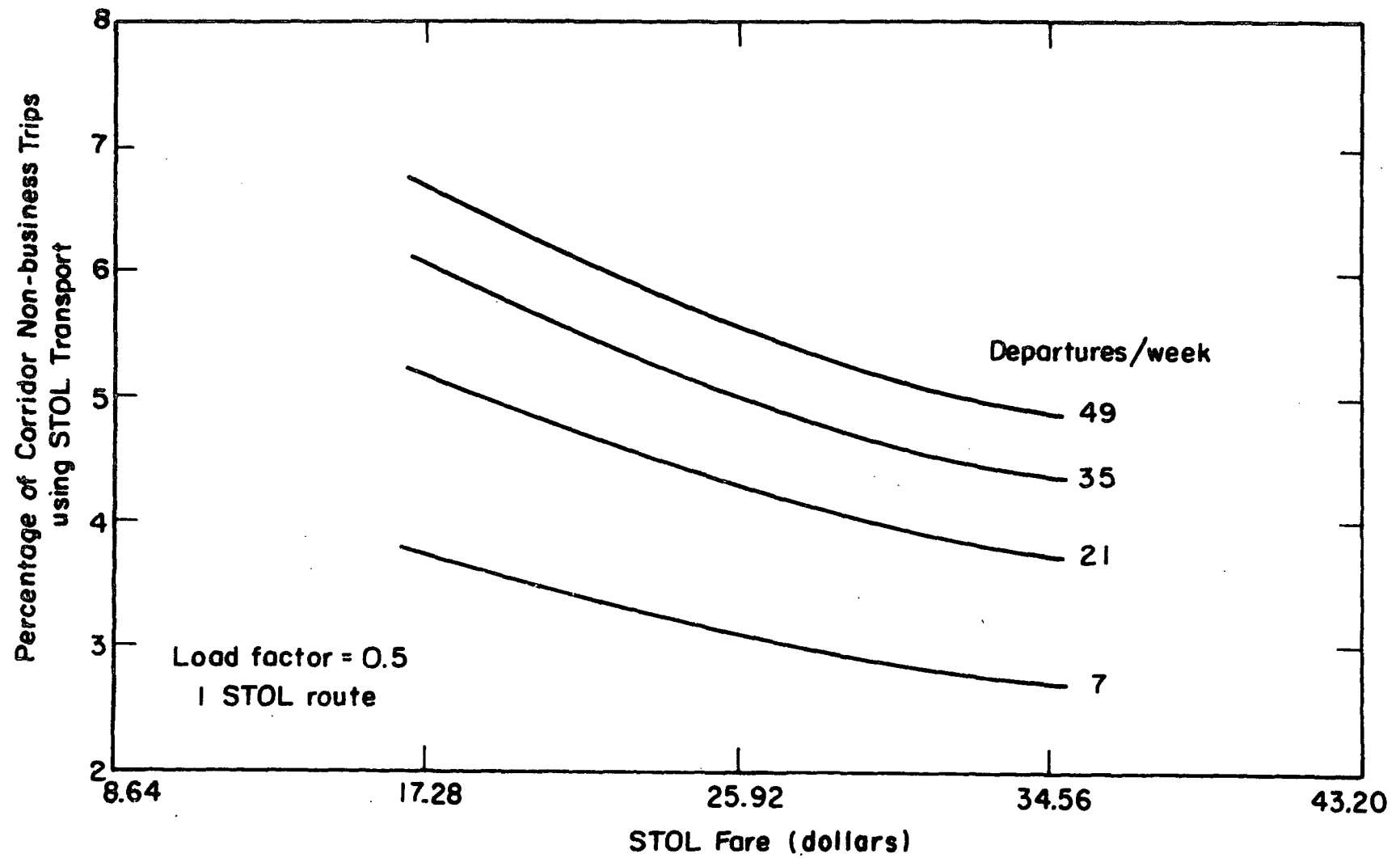


Figure 5-8 Sensitivity of STOL Share of the Non-Business Travel Market to STOL (Configuration I)

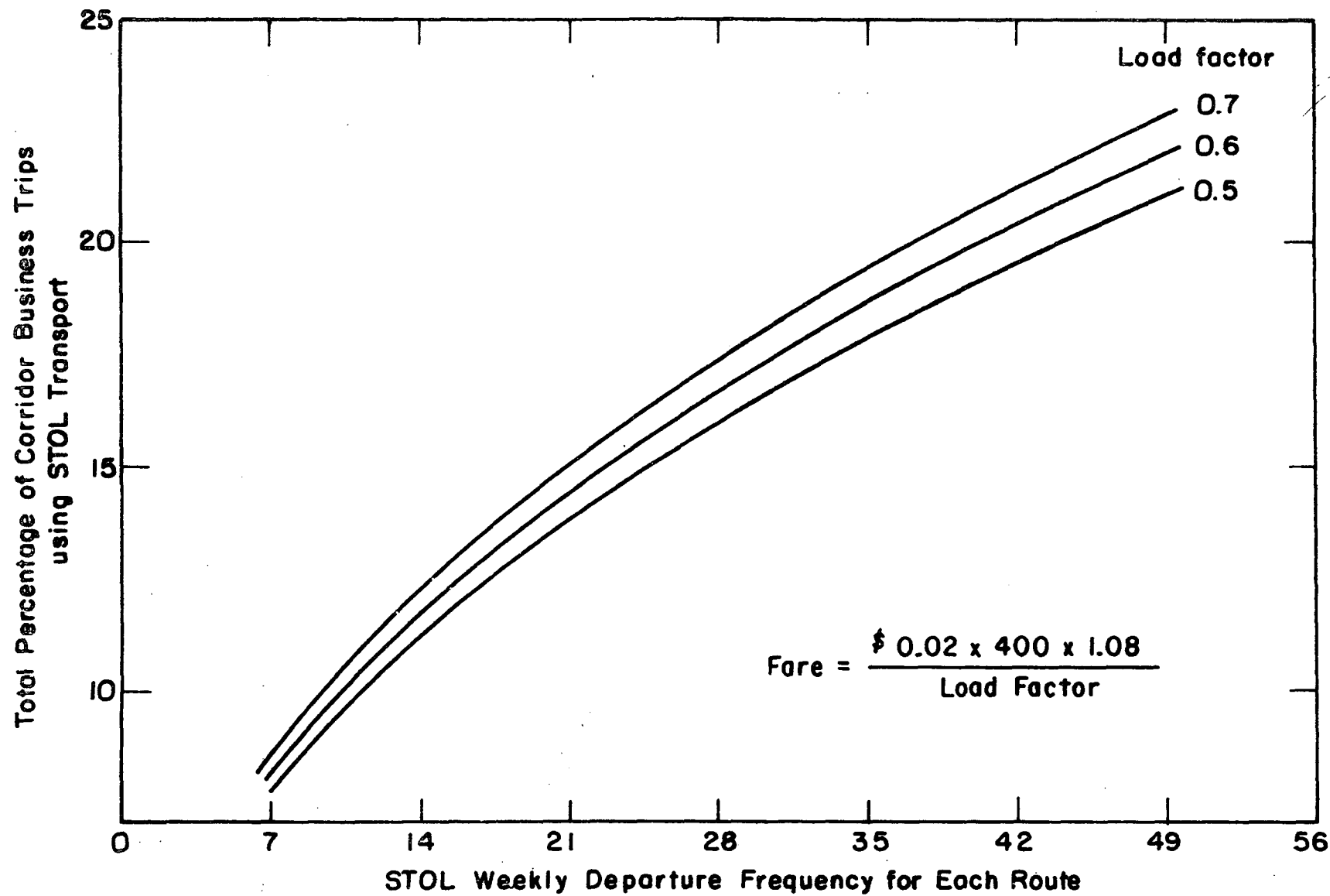


Figure 5-9 Sensitivity of STOL Share of the Business Travel Market to Departure Frequency (Configuration II)

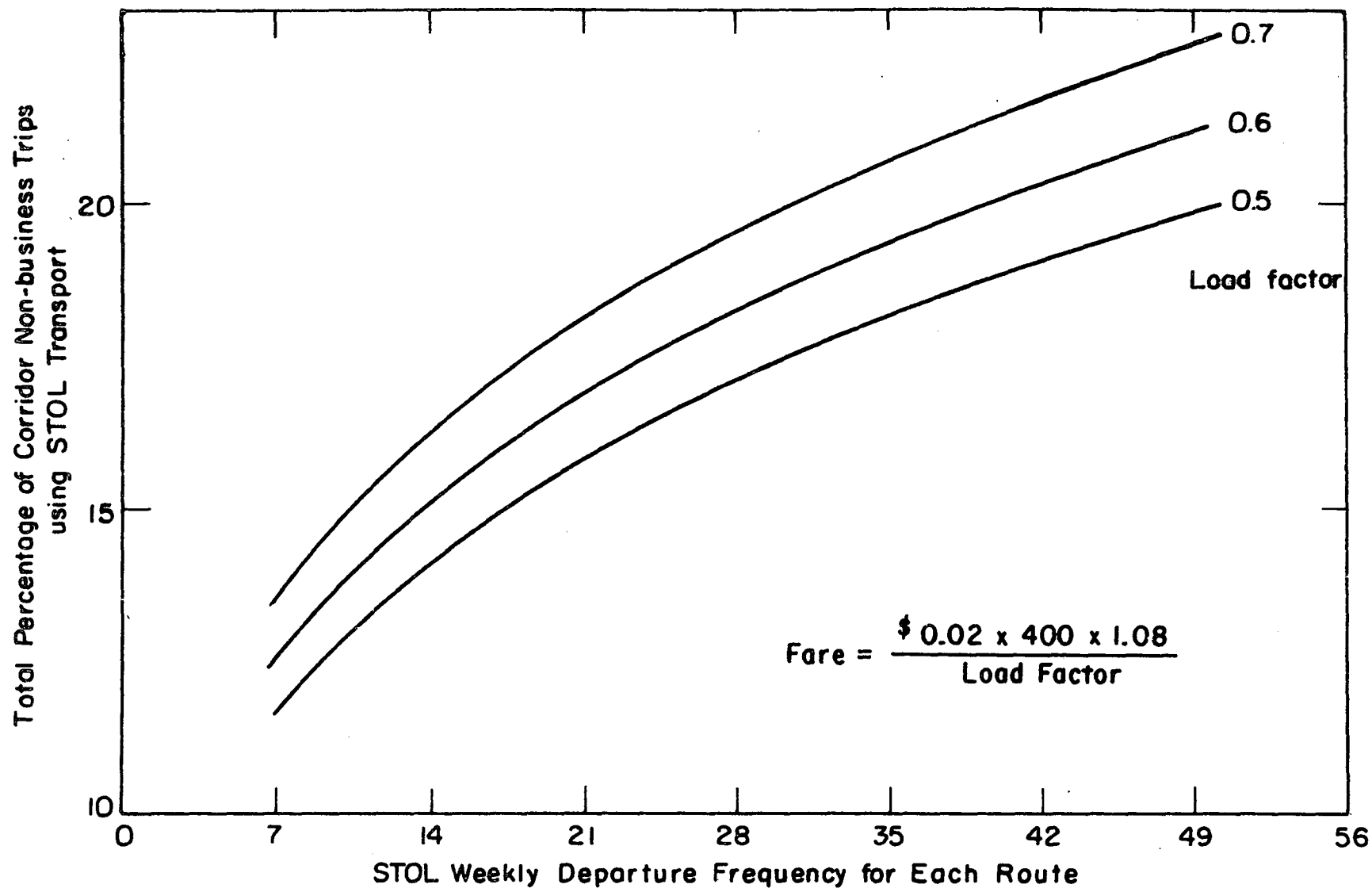


Figure 5-10 Sensitivity of STOL Share of the Non-Business Travel Market to Departure Frequency (Configuration II)

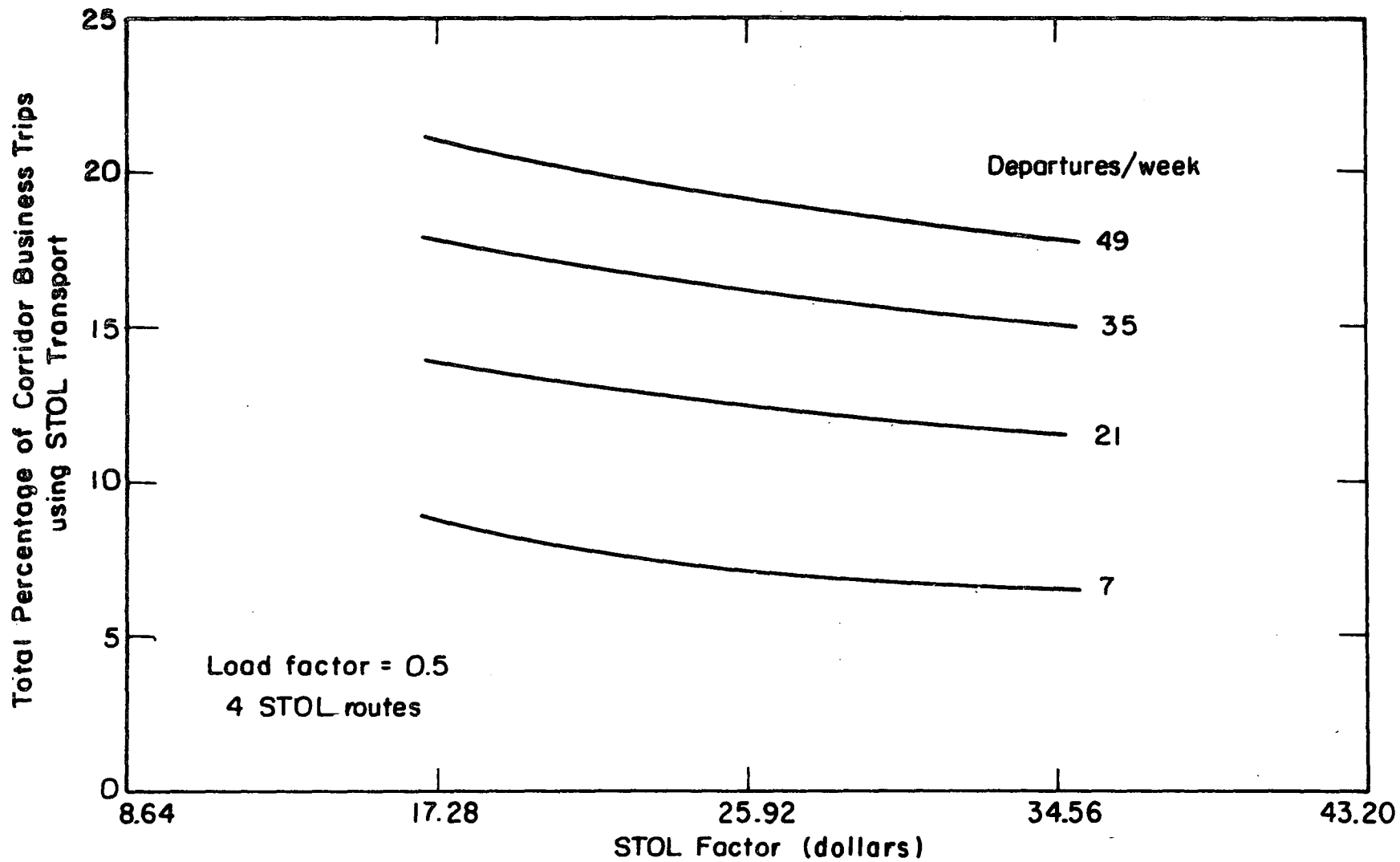


Figure 5-11 Sensitivity of STOL Share of the Business Travel Market to STOL Fare (Configuration II)

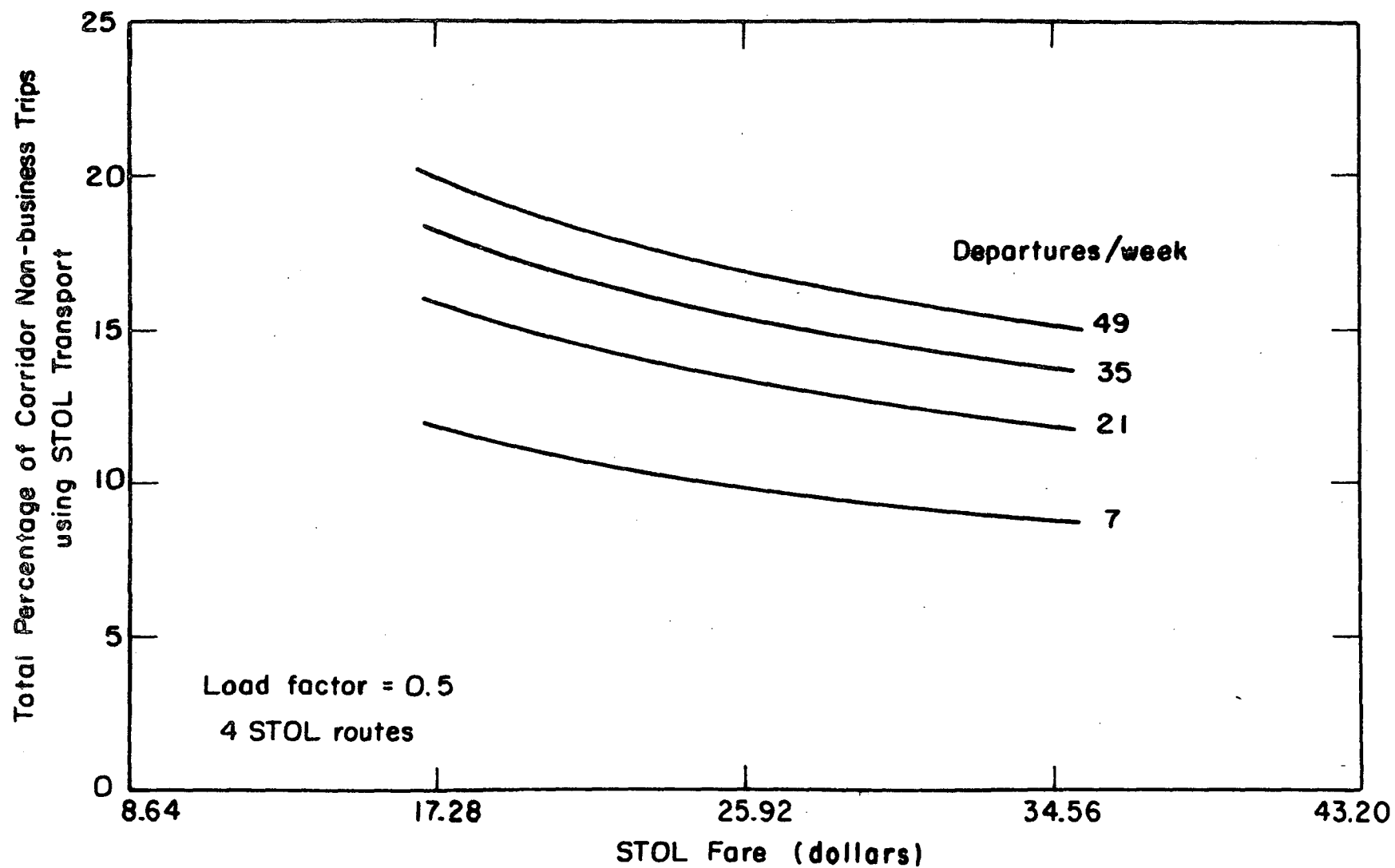


Figure 5-12 Sensitivity of STOL Share of the Non-Business Travel Market to STOL Fare (Configuration II)

CTOL schedule frequencies simultaneous to increases in STOL frequencies. This was done in two manners. First, reductions in total CTOL frequencies ranging from 10 to 90 percent were obtained by switching these flights into STOL and distributing them equally among STOL-ports in each configuration studied. Second, CTOL frequencies were reduced at only routes involving either San Francisco International or Los Angeles International or both by switching flights to STOL and distributing them among STOL-ports in the same manner as before. This second case was motivated by the idea that STOL service may be introduced to reduce congestion at the major hub airports. Since only San Francisco International and Los Angeles International may have levels of volume sufficiently high to cause congestion, it was assumed that CTOL service reduction may be warranted at routes including either or both of those two airports.

The results of this analysis are shown in Figs. 5-13 and 5-14 for configuration I. The figures show the increase in STOL market share related to the two types of CTOL frequency adjustments described above. The results shown in the figures are based on a STOL air fare derived from a rate of 3¢ per available seat mile and a load factor of 60 percent. [1]

With the reduction in CTOL schedule frequency, it can be seen that the market share potential for STOL has now risen. For STOL system configuration I a market share of over 50 percent can be achieved, as compared to a maximum of 7 percent if CTOL service is maintained without

[1] With a basic rate of 3¢ per available seat mile and a load factor of 60 percent a STOL fare of \$21.60 is obtained, based on a stage length of 400 miles and an 8 percent tax.

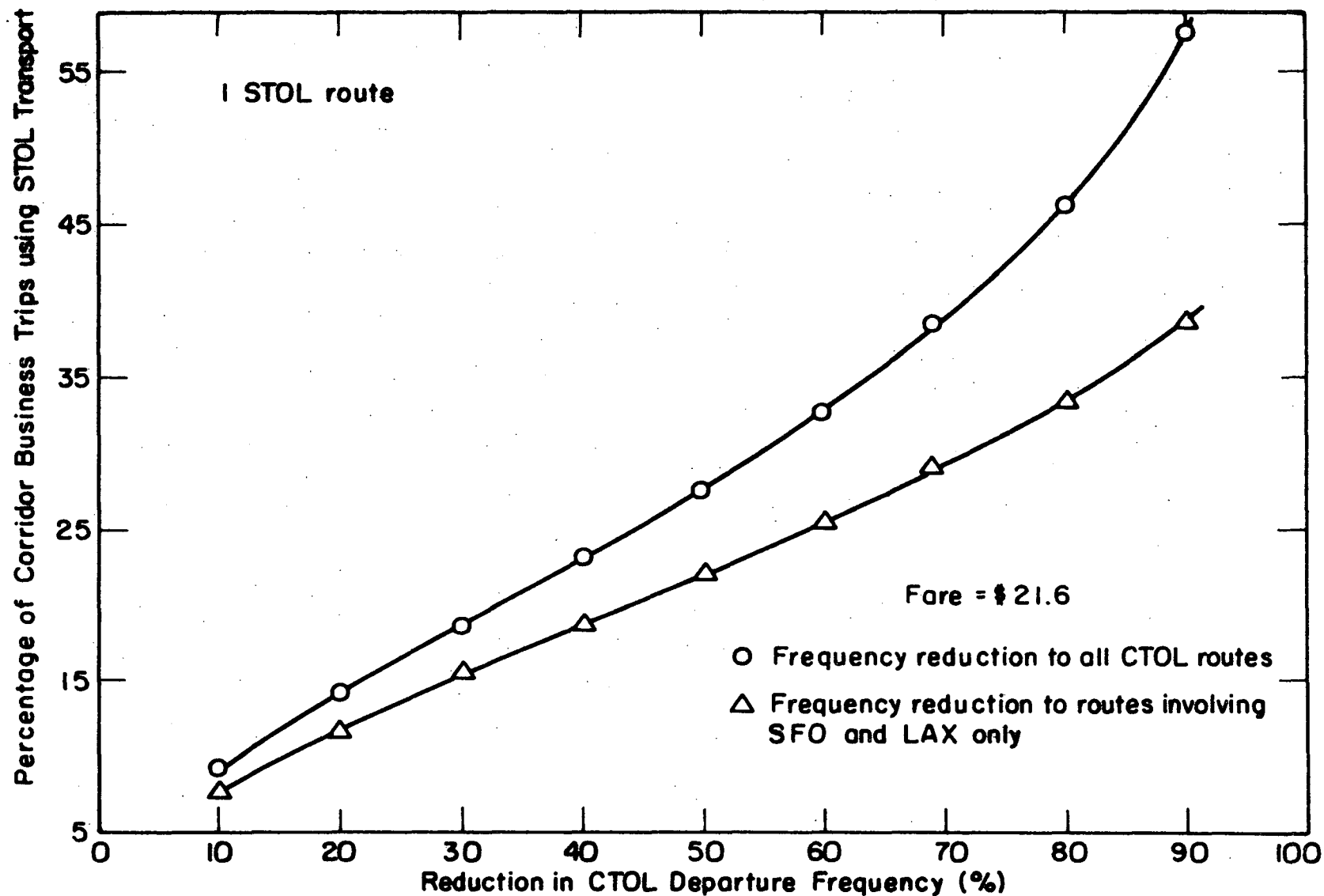


Figure 5-13 Sensitivity of STOL Share of the Business Travel Market to Changes in CTOL Departure Frequency (Configuration I)

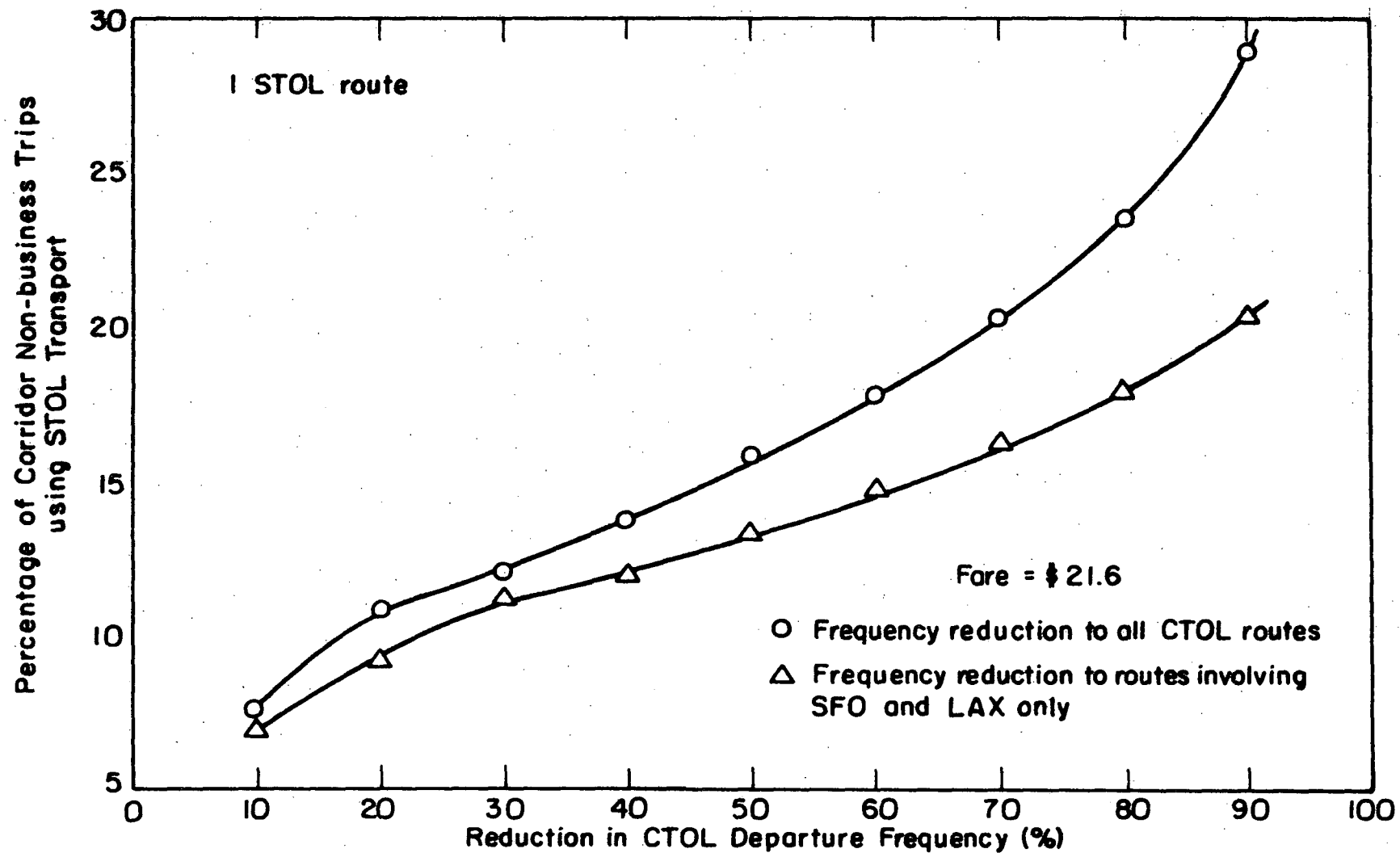


Figure 5-14 Sensitivity of STOL Share of the Non-Business Travel Market to Changes in CTOL Departure Frequency (Configuration I)

reductions in frequency.

The same analysis was repeated with STOL system configuration II. Using the same fare and the same ranges for frequency changes, STOL market share potential increases now to a maximum of about 70 percent, as shown in Figs. 5-15 and 5-16. It should be noted that for both configurations the increase in business travel is larger than the increase in non-business travel. This result follows from the fact that business travel is more sensitive to service frequency as was demonstrated earlier.

An interesting result is obtained when one compared Figs. 5-13 and 5-14 to Figs. 5-15 and 5-16. In spite of the fact that in both cases the number of flights switched from CTOL to STOL service is the same, the market share potential under configuration II is larger than under configuration I. This seems to indicate that market share increases as the number of STOL-ports increases, even if the same service frequency is maintained. It seems that STOL demand is sensitive to the available choice of STOL-ports. Of course, this sensitivity is for the most part, due to the fact that a larger number of STOL-ports will yield a larger accessibility to STOL services in general.

The same analysis was repeated with STOL system configurations III and IV. In configuration III Fullerton airport is replaced by Long Beach Airport. In this case it was assumed that the CTOL service at Long Beach Airport is eliminated, and replaced by the airport's share of the total STOL frequencies. The results obtained in this case are shown in Figs. 5-17 and 5-18 for the business and non-business cases, respectively. These results show no significant difference from those

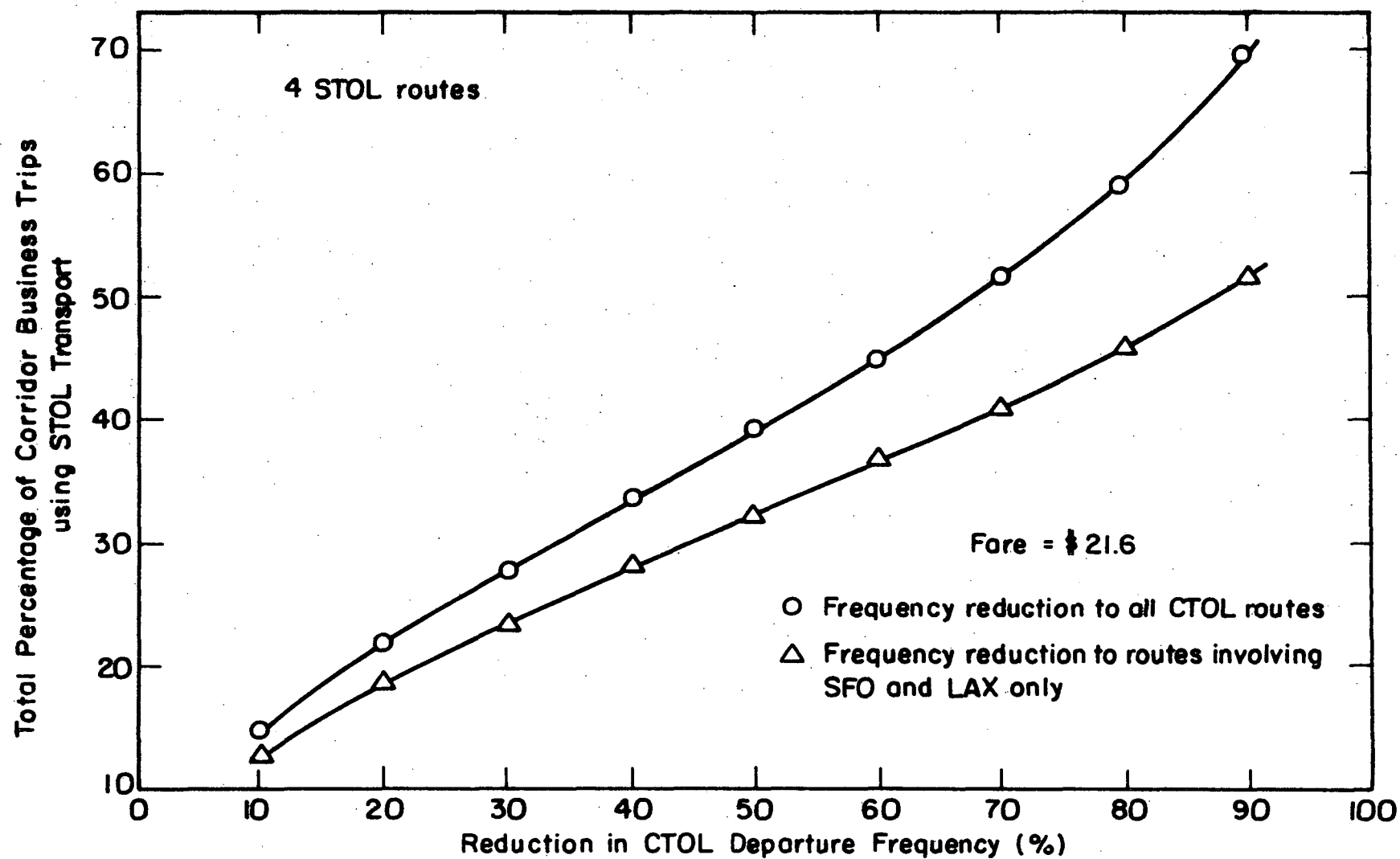


Figure 5-15 Sensitivity of STOL Share of the Business Travel Market to Changes in CTOL Departure Frequency (Configuration II)

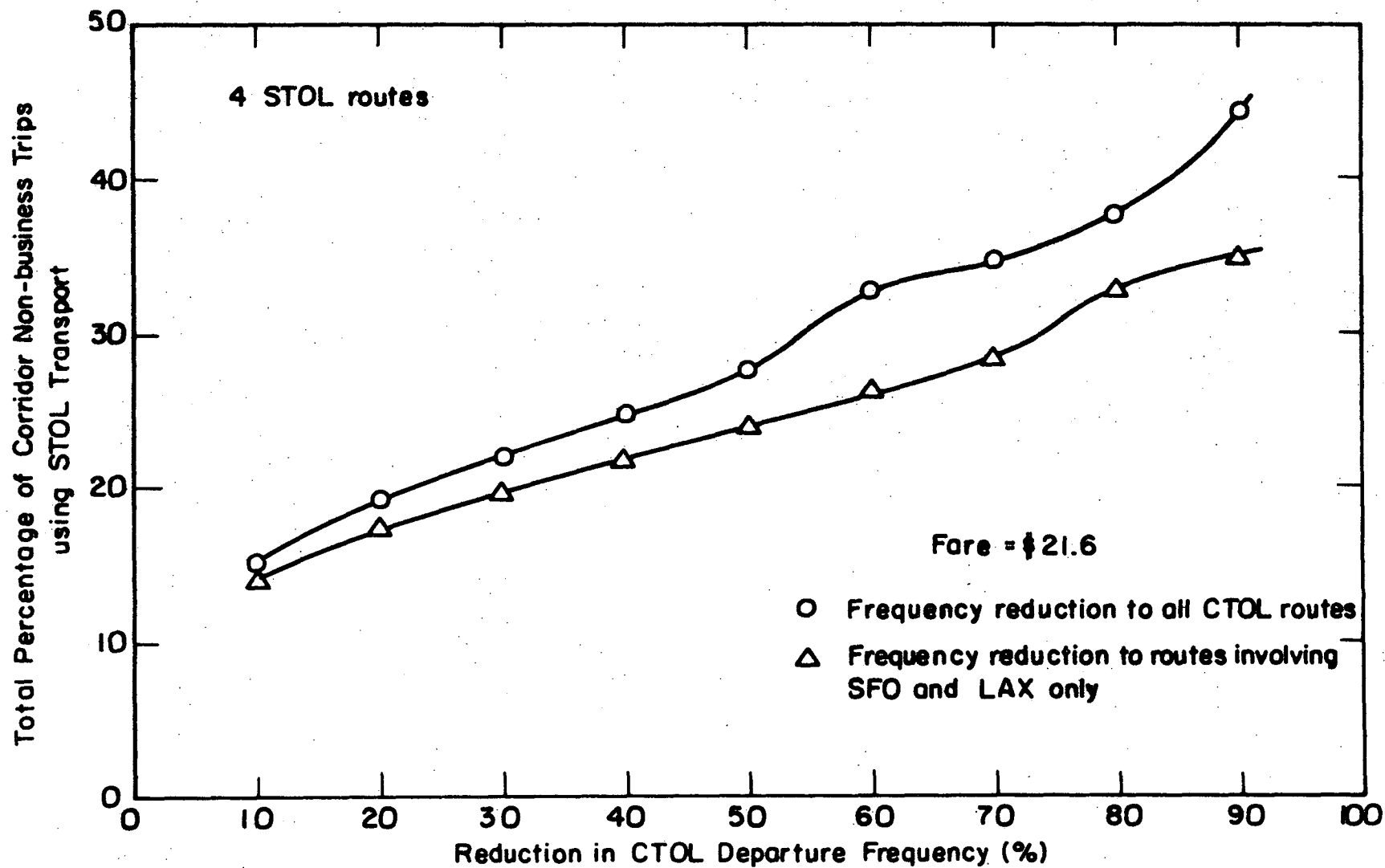


Figure 5-16 Sensitivity of STOL Share of the Non-Business Travel Market to Changes in CTOL Departure Frequency (Configuration II)

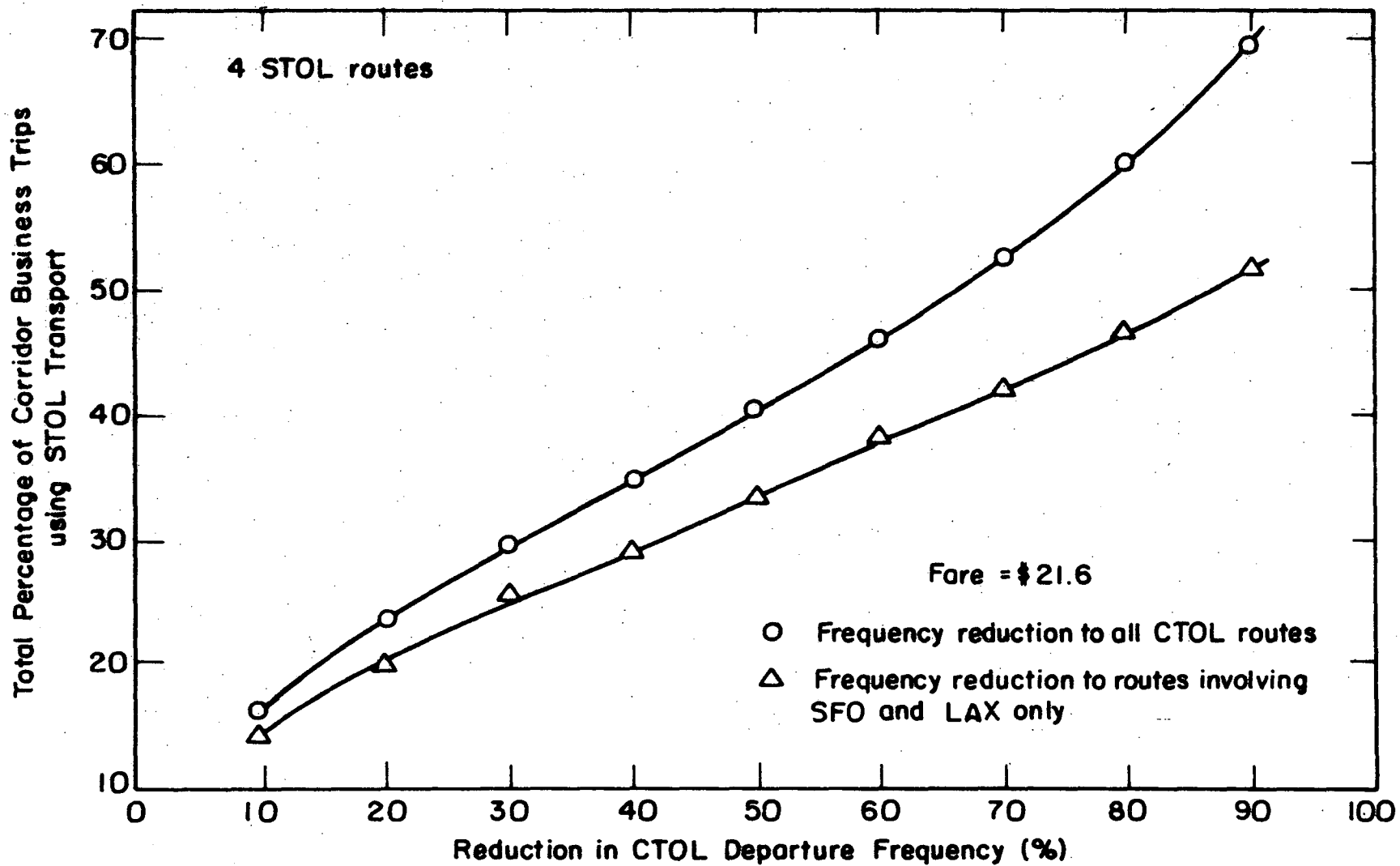


Figure 5-17 Sensitivity of STOL Share of the Business Travel Market to Changes in CTOL Departure Frequency (Configuration III)

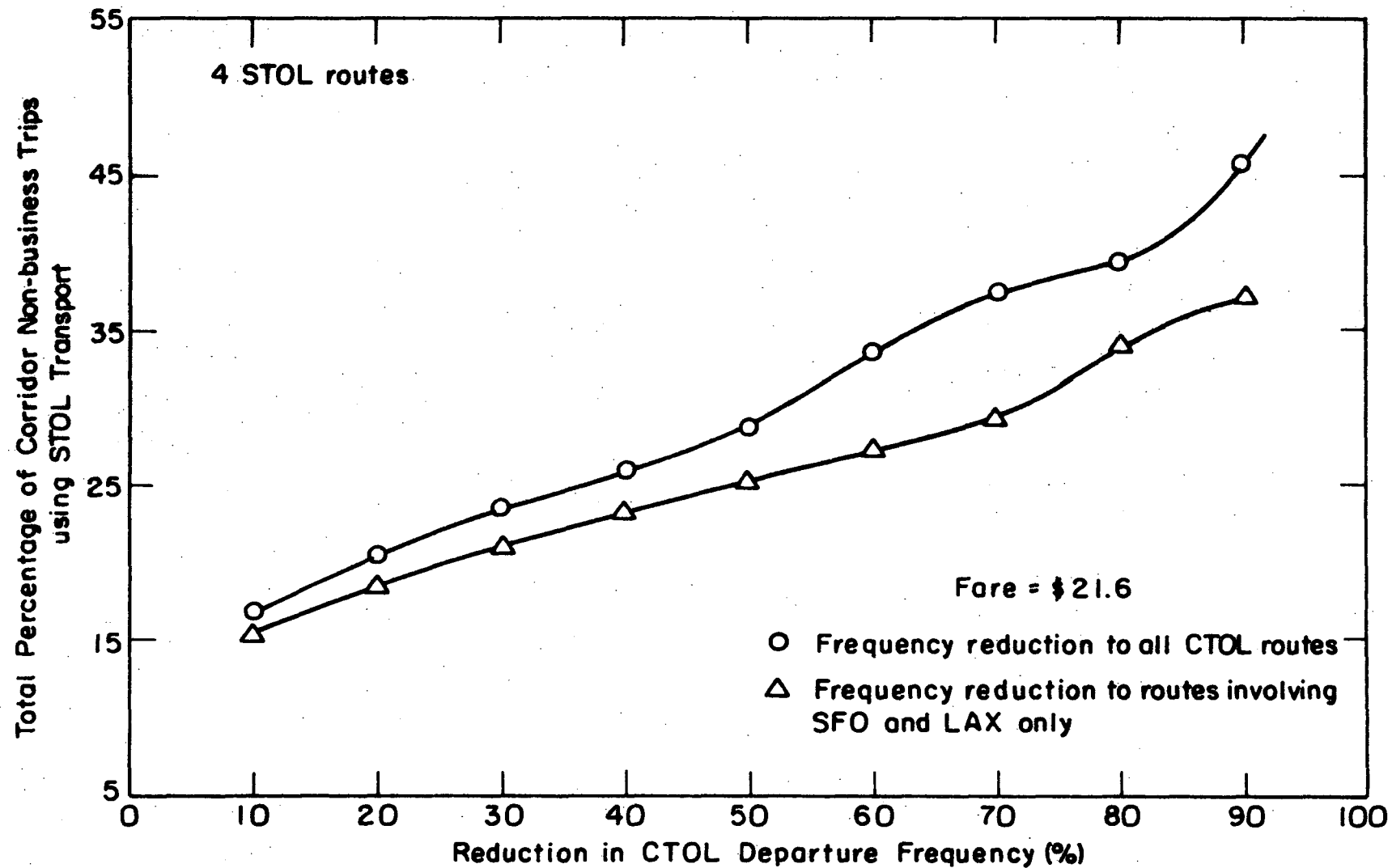


Figure 5-18 Sensitivity of STOL Share of the Non-Business Travel Market to Changes in CTOL Departure Frequency (Configuration III)

of configuration II. The reason for this is that the present share of Long Beach Airport of the total corridor service is quite small.

The results obtained with configuration IV and shown in Figs. 5-19 and 5-20, show an interesting trend. With configuration IV there are six STOL-port pairs as compared to 4 in configurations II and III. By comparing the results obtained with configurations I, II or III, and IV, it can be seen that the increase in STOL market share achieved by increasing the number of STOL routes from 1 to 4 is larger than that obtained in going from 4 to 6 routes. For example, for a 50 percent reduction in CTOL frequency on routes involving either San Francisco or Los Angeles or both, the market share for configuration I is approximately 22 percent for business travel, as shown in Fig. 5-15. The corresponding figures for configuration II and IV are approximately 32 percent and 37 percent respectively, as shown in Fig. 5-17 and 5-19.

These results indicate that the marginal increase in STOL market share is decreasing as the number of STOL-ports increases. A result such as this is of vital importance when studying the cost-effectiveness of introducing additional STOL-ports into an urban area.

Forecasting STOL Demand Potential: It is possible now to combine the forecasts of the total corridor air travel demand with the forecasts of the STOL market share to obtain a forecast of the total STOL demand potential. This is a simple operation consisting of the multiplication of the STOL share with the total volume. As an example, the forecast for configuration I was obtained, for business travel, for various levels of frequency switch from the CTOL airports to the STOL-ports. The forecast results are shown in Fig. 5-21. They are based on a

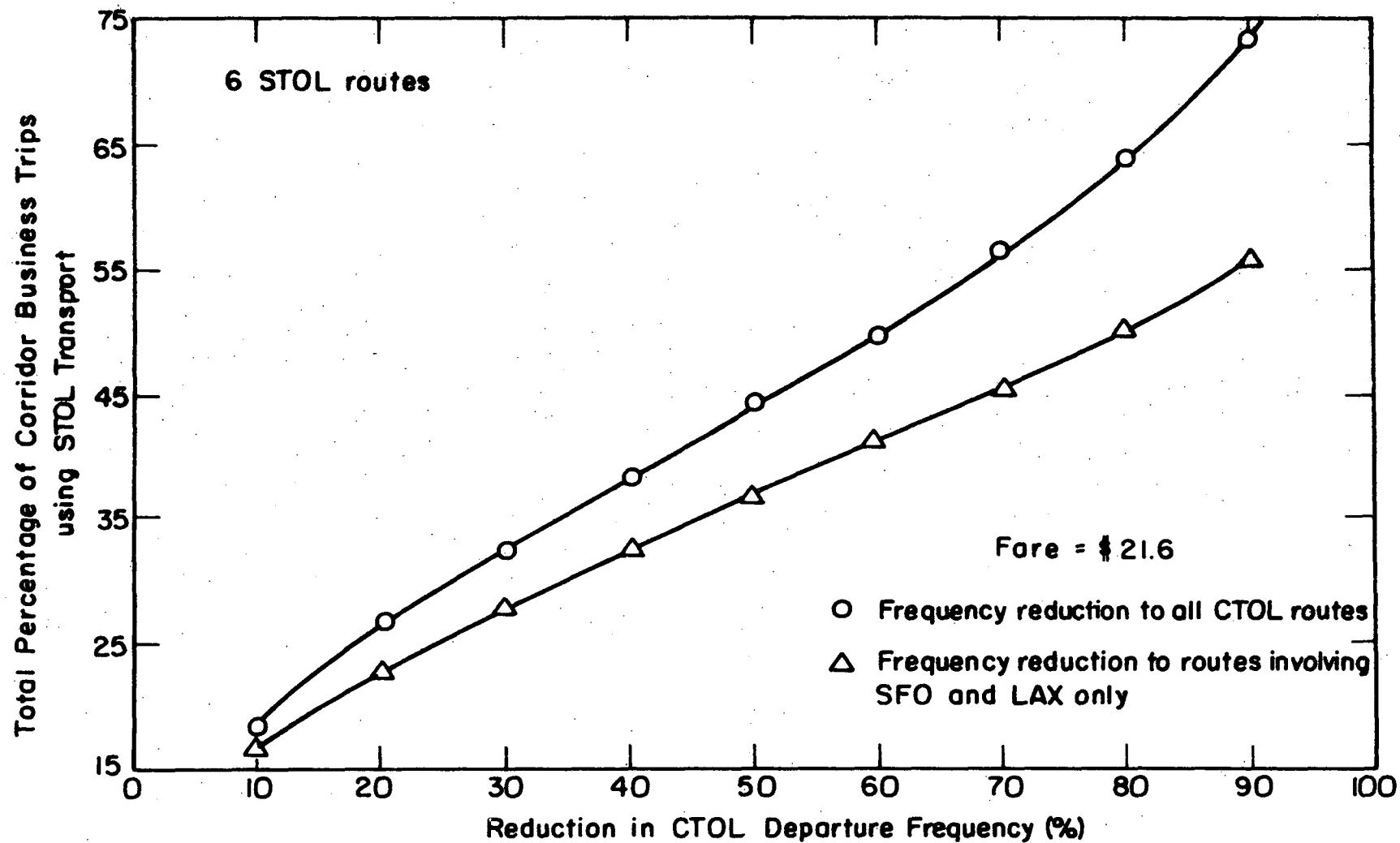


Figure 5-19 Sensitivity of STOL Share of the Business Travel Market to Changes in CTOL Departure Frequency (Configuration IV)

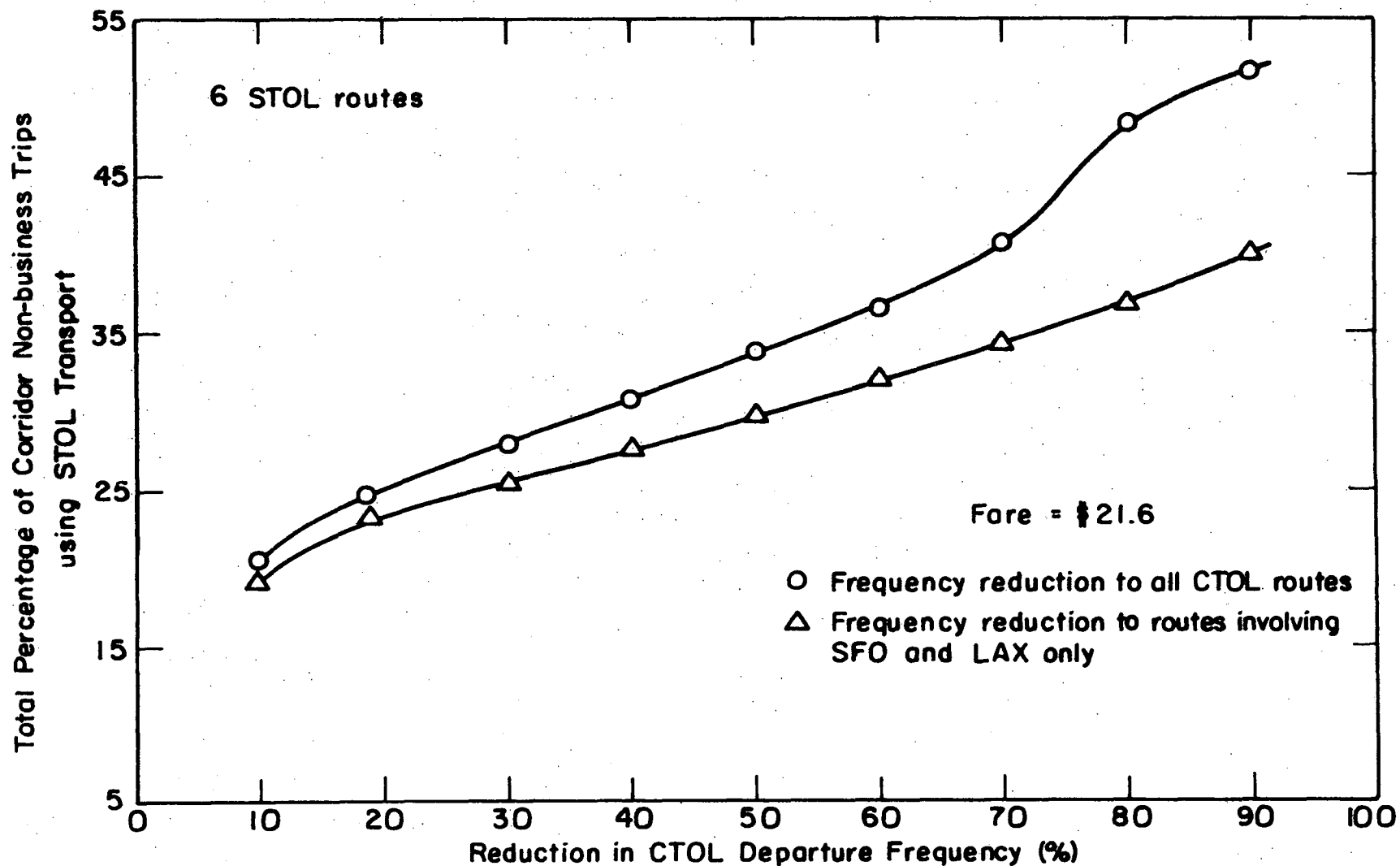


Figure 5-20 Sensitivity of STOL Share of the Non-Business Travel Market to Changes in CTOL Departure Frequency (Configuration IV)

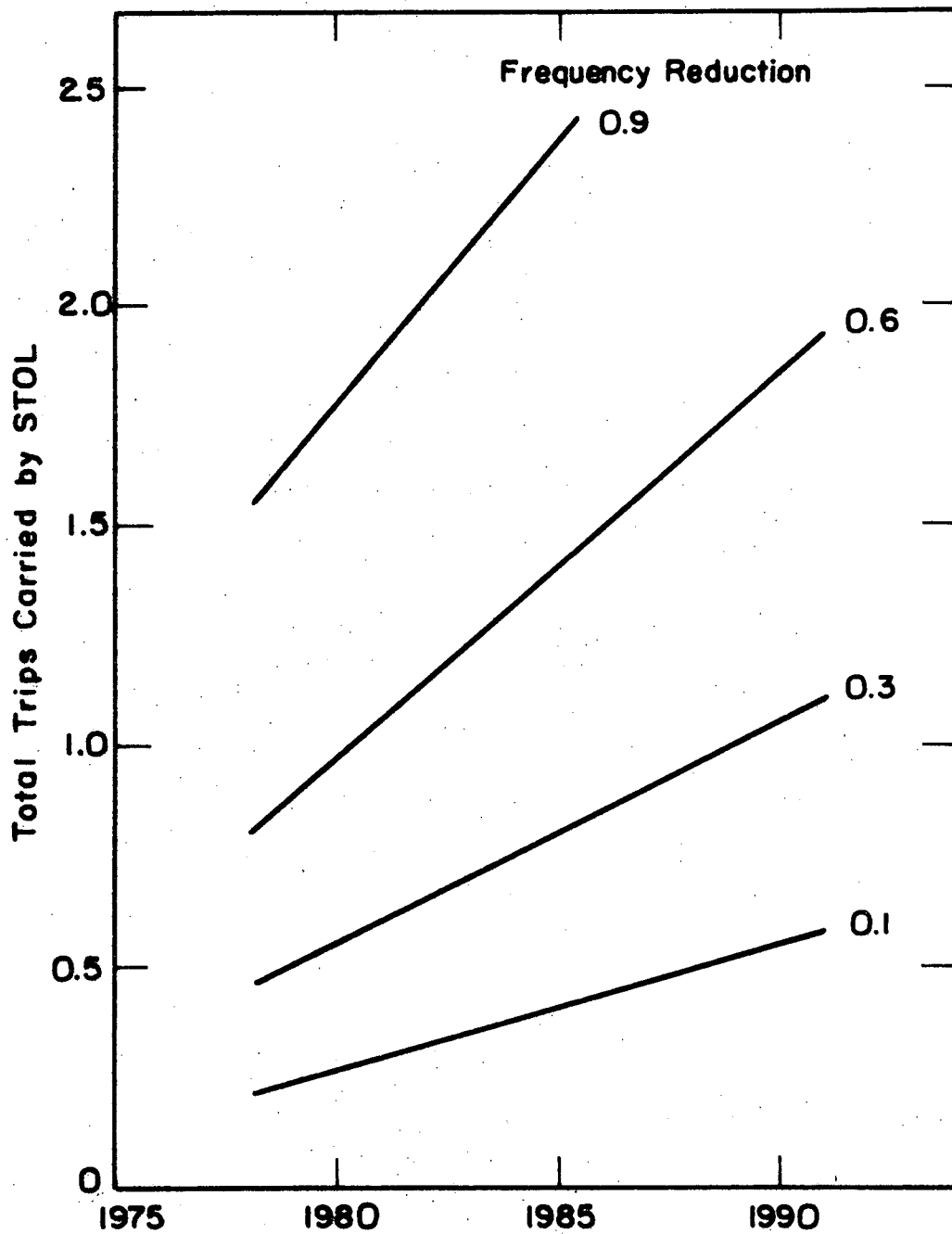


Figure 5-21 Forecast of STOL Transport Demand Generated by Configuration One
with Frequency Reduction to all CTOL Routes

population growth rate of 0.5 percent per year, and median income increase of 7 percent per year and a STOL rate of \$21.60 including tax. Starting with a 1970 base year total volume of 3.1 million passengers, the forecast extends to 1990. Naturally, the validity of a forecast through 1990 depends on the validity of the assumed growth rates for population and income. These growth rates could be modified at intervals within the forecast period if this is deemed necessary.

The purpose of this example is simply to demonstrate the use of the calibrated models and forecasting techniques in obtaining an estimate of the total STOL demand potential in the study area.

SUMMARY

The results of the applications of the models to forecasting air travel demand in the study area were presented in this chapter. The forecasting of total travel generation is a process of using demand elasticities to relate the growth in traffic to the growth in socioeconomic characteristics and to the changes in transportation system characteristics. The forecasting of the STOL market share is essentially done in the form of a sensitivity analysis.

In the examples presented in this Chapter it was observed that business travel is more sensitive to schedule frequency than non-business travel. It was also observed that air fare has a stronger impact on non-business travel than it does on business travel. These results corroborate and confirm the similar results obtained in model calibration, as described in Chapter 4.

It was also observed by comparing the forecasts for different STOL system configurations that the effect of the available number of STOL routes in an air travel market on the STOL share of that market is important. This is mainly due to the increased accessibility that a larger number of STOL-port locations in an urban area offers. However, it was also observed that the importance of the number of STOL-ports decreases as the number increases. This result is important for performing cost effectiveness analysis of alternative STOL system configurations.

The process of forecasting the demand potential for STOL transportation is a simple process. It consists of combining the results of forecasts of total travel generation and of STOL market share, as was demonstrated by an example.

CHAPTER 6

SUMMARY AND CONCLUSIONS

This study demonstrates the use of a system of three models for forecasting the demand potential for STOL transportation. The first, is the travel generation model, which estimates the total air travel demand in the study corridor. The second is the choice model which estimates the distribution of the demand among the different routes in the corridor. Finally, the third is the STOL demand model which combines the results of the first two models to provide a forecast of the demand potential for STOL.

The calibration of the models was performed using data for the San Francisco-Los Angeles air travel corridor. The calibration showed that the models were good representations of the behavior of the air transportation system in the study corridor, and that they were capable of providing reliable demand forecasts.

Sensitivity analysis was used in this study to forecast the demand potential for STOL. This approach was selected because of the inability to predict accurately the characteristics of future STOL systems. Thus, varying ranges of systems characteristics were postulated and the corresponding STOL demand levels were forecast. It is believed that this type of forecasting allows the planner flexibility in selecting alternative STOL system configurations, and evaluating their economic feasibility on the basis of their demand potential.

Sensitivity analysis was also applied to forecasting total air travel demand in the study corridor. It was determined upon calibration of the travel generation models, that these models could not be used to provide

reliable forecasts of total air travel demand. This was due to the fact that the models failed to adequately explain the observed travel patterns; and the unavailability of data needed to specify alternative models. However, the estimates of demand elasticities with respect to socio-economic and transportation variables were quite significant. Therefore, these elasticities were used, and demand forecasts were obtained by relating proportional changes in the observed travel demands to proportional changes in variables such as population and income. Various growth trends for these variables were postulated and the corresponding growth trends in travel demand were forecast.

Major Findings and Conclusions

The following is a list of the major findings of the study. These findings were observed at various stages of the project; some appearing during the calibration phase, and some during the sensitivity analysis phase. It is important to recognize that these findings are based on one study area: the San Francisco-Los Angeles corridor. Care should be taken in generalizing these findings to air transportation as a whole.

1. Of the three transportation characteristics: travel time, travel cost, and schedule frequency, the last seems to have the strongest effect on the traveler's choice among available routes. In all trip purpose cases, the demand elasticity to frequency was significantly larger than elasticities to either travel cost or travel time. From this it can be concluded that air travelers in the study area seem to be more sensitive to delays due to the unavailability of convenient schedules, than they are to ground access delays. This is not surprising since access times within the study area vary within a range relatively small compared to the variations in schedule frequencies.

2. Of the three trip purposes: work related business, personal business,

and recreation, the first is the most predominant in the study corridor, constituting approximately 50 percent of the total travel volume. Business travelers appear to be more sensitive to schedule frequency than non-business travelers, but less sensitive to travel cost.

3. The growth in both income and population seem to have a significant effect on the growth in air travel demand. However, income growth appears to have over three times the effect of population growth. Air travel demand in the study corridor can be expected to follow economic trends more closely than demographic trends.

4. Air travel demand in the study area does not appear to be influenced significantly by ground access time. However, this does not mean that ground access is not an important consideration in air transportation.

5. The demand potential for STOL depends strongly on the number of STOL-ports in the system and on frequency of STOL service. The forecasting results indicate that the demand potential for STOL is strongly affected by the diversion of short haul service from CTOL to STOL.

From this it can be concluded that the demand potential for STOL depends strongly on the characteristics of the system. Therefore, a true assessment of this potential cannot be made, until more is known about the characteristics of the system. These characteristics include the locations of STOL-ports; the frequencies of both STOL and CTOL service; and the fare structure of both.

Suggestions for Further Research

The results of this study suggest a number of interesting and potentially worthwhile future research efforts. The first such effort would be aimed at the refinement of the methodology developed in this study. The combination of a model of the economics of STOL operation with the forecasting model would

be a significant improvement to the methodology. This combination would allow the study of the feedback that exists between the supply and the demand for STOL transportation. An understanding of this feedback would allow a more efficient estimation of its equilibrium, and thus more reliable forecasting.

Other avenues for further research involve the use of the forecasting models in the evaluation of the feasibility of alternative STOL systems. One worthwhile research effort would be to perform a cost-effectiveness analysis of providing additional STOL-ports in a STOL system. The use of the forecasting models would be a part of such an analysis. Another avenue for research would be to extend the use of the forecasting models to the optimization of STOL-port locations within metropolitan areas. Demand potential would be one of the performance measures used in the optimization process. Others would include infrastructure costs, environmental impacts, and access levels of service.

In summary, the different directions that further research in the area of STOL systems analysis can take are many. On the other hand, many elements of the system need to be studied before its feasibility can be truly evaluated.

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